# EVERYDAY PHYSICS

## A LABORATORY MANUAL

PACKARD

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# EVERYDAY PHYSICS

## A LABORATORY MANUAL

BY

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# PREFACE

This laboratory manual is intended to outline a course in physics for secondary schools, adapted equally well to preparation for college and to the immediate requirements of everyday life. With this end in view the author has combined under the title of this book a large number of the more practical exercises recently developed in the high-school laboratory with a selected number of exercises from the standard list, in such a manner as to conserve the best elements of the college course while emphasizing the latest and most approved ideas of the modern school. The standard exercises have been restated in the interest of clearness and for the sake of maintaining the spirit of the book throughout, but so far as possible standard apparatus has been made use of in this part of the work. The newer exercises involve the use of commercial apparatus, easily procured though varying slightly in form in different localities. It is not intended that all the exercises should be handled in precisely the same manner: some (6, 14, 23, 33, 36, 57, 59) are best adapted to the group method; others (1-4, 7, 10, 20, 21, 26, 37, 45) to the individual method, and a few (11, 12, 27, 36) to the method of classroom demonstration. Wide latitude is given to the individual teacher in each case. An abundance of suggestions for home work, dealing with the most useful applications of the principles of physics to the affairs of everyday life, is a prominent feature of the course.

The beginner in science must be guided carefully in his early experiments if he is to develop habits of careful observation, clear thinking, and orderly presentation of results. The exercises in this manual have been carefully designed and the instructions definitely stated, in order that the pupil may see clearly the end in view and the method of procedure, with the least possible amount of assistance on the part of the instructor in charge. On the other hand, the pupil must be given a chance to think for himself if he is ever to develop a scientific imagination or to acquire initiative. Under the head of Topics for Further Study and Investigation, hints, topics, and suggestions have been freely given for the development of projects in connection with which the pupil is expected, of his own initiative, to gather information from trade catalogues and textbooks, from practical men at work in his vicinity, or from observations at home, and to draw his own conclusions and report the results. A practical exercise offered under this head may often be substituted with profit for a more formal exercise outlined in the body of the text. Special credit should be given in each case for this part of the work, and the pupil should be encouraged to make this department an important feature of his course.

Nearly every exercise is preceded by an Introduction, intended to show the bearing of the topic in hand upon related subjects or to make the object of the exercise a little more definite, and is followed, usually, by a few carefully framed questions or problems emphasizing the immediate application of the principle involved to the affairs of daily life.

This manual has been developed so slowly that the author cannot undertake, at this time, to trace each idea to its original source or to credit everyone who has contributed to its unfolding, but in common with other writers he takes pleasure in referring to *School Science and Mathematics*, to the reports of the Committee on Physics of the National Education Association, to the publications of the Eastern Association of Physics, and to the list of Harvard College Entrance Requirements. Cuts and descriptive matter from trade catalogues have been used freely, and the author is of the firm conviction that much valuable material for every department of science can be gathered from such sources, to the mutual benefit of the tradesmen and the school. A list of commercial houses distributing interesting catalogues can be made up from advertisements in the trade journals, and the laboratory should keep on hand a large variety of such catalogues, for the use of pupils in the study of projects. The larger commercial houses will doubtless be glad to coöperate in this matter. The *Form of Record* shown in connection with certain quantitative exercises is intended to illustrate the tabular method of recording results, — invaluable in many cases but not to be followed too slavishly. Such a record should be preceded in the notebook by a brief statement of the apparatus used and the method employed to accomplish the stated object of the exercise. Such notes, comments, and conclusions as will serve to make the notebook of value in review and in connection with applied science in other subjects should be freely added. The object of a laboratory course in physics is not to make a notebook but to teach the principles of physics and to emphasize their practical application. This manual may be used in connection with any of the better class of textbooks in physics, or it may be used without any other book. The author is deeply indebted to Mr. John W. Hutchins of the Malden (Massachusetts) High School for a careful review of the proof and for valuable suggestions; he holds himself solely responsible, however, for any errors that may appear in the text.

J. C. P.

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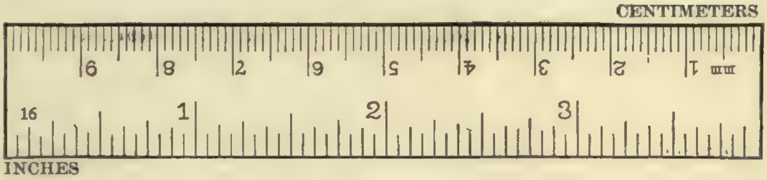
# EVERYDAY PHYSICS

## 1. STUDY OF A METRIC RULE

### THE INCH AND THE CENTIMETER



**Apparatus.** Two thirty-centimeter metric rules or two half-meter sticks graduated on one side into inches and on the other side into centimeters and tenths of centimeters, or millimeters.

The figure shows an ordinary steel ten-centimeter metric rule, useful as a pocket piece. Why does the engineer prefer a steel tape measure to a linen one? Why are rules so often made of boxwood?

#### INTRODUCTION

The metric system of weights and measures is commonly used in the laboratory, precisely as the English system of weights and measures is used in our everyday life. With a little effort one can soon learn to use either system at will. The first four exercises in this manual are intended to illustrate the use of the centimeter as the unit of length and the gram as the unit of weight, while serving at the same time as a brief review of decimals and to give practice in the use of formulæ.

#### EXERCISE

Copy the *Form of Record* into your notebook; write nothing whatever in the laboratory manual.

Place the two rules edge to edge, the inches on one rule beside the centimeters on the other, and try to determine by a close observation, reading to tenths of centimeters and estimating to hundredths if need be, how many centimeters there are in five inches. Record under *Data*. From this one fact compute the facts required to complete the tabular statement, and record. Do not use more than two decimal places in any part of the work. Why? Illustrate your report by a sketch showing the two rules in place for direct comparison.

(*Form of Record*)

STUDY OF A METRIC RULE

THE INCH AND THE CENTIMETER

*Data*

5 inches = ........................................ centimeters

*Computations*

1 in. = ........................................ cm.
1 cm. = ........................................ in.

1 sq. in. = ........................................ sq. cm.
1 sq. cm. = ........................................ sq. in.

1 cu. in. = ........................................ cc.
1 cc. = ........................................ cu. in.

## PROBLEMS

**1.** Express in metric units:
1 ft. (= ......... cm.); 1 yd.; 2 ft. 3 in.; 7 ft. 7 in.; $\frac{7}{8}$ in.; $\frac{3}{4}$ in.; $14\frac{7}{8}$ in.; 30 in.; $3\frac{7}{8}$ sq. in.; $2\frac{8}{9}$ cu. in.

**2.** Express in English units:
25 cm. (= ......... in.); 3.95 cm.; 76 cm.; 67 cm.; 30 cm.; .95 cm.; 2.56 sq. cm.; 3.9 cc.

**3.** Make a careful drawing, full size, of a square inch; of a square centimeter.

**4.** Make a careful drawing, full size, of a cubic inch; of a cubic centimeter.

## TOPICS FOR FURTHER STUDY AND INVESTIGATION

The metric system; English equivalents.

## METRIC TABLES

### *Length*

**10 millimeters = 1 centimeter**
**10 centimeters = 1 decimeter**
**10 decimeters = 1 meter (39.37 inches)**
**10 meters = 1 dekameter**
**10 dekameters = 1 hectometer**
**10 hectometers = 1 kilometer (about $\frac{5}{8}$ mile)**

### *Weight*

**10 milligrams = 1 centigram**
**10 centigrams = 1 decigram**
**10 decigrams = 1 gram (.035 ounces)**
**10 grams = 1 dekagram**
**10 dekagrams = 1 hectogram**
**10 hectograms = 1 kilogram (2.2 pounds)**

The unit of capacity is the liter (1000 cc.); it is equivalent to about one quart.

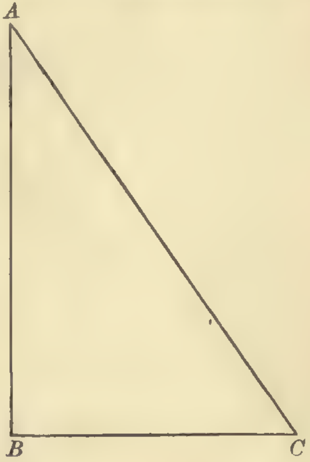
## 2. STUDY OF A CIRCLE AND A TRIANGLE

### CIRCUMFERENCE; AREA

**Apparatus.** A pair of dividers; metric rule.

#### EXERCISE

On a page of your notebook describe a 2-inch circle (diameter 2 in.) and construct a right triangle *ABC* (see illustration) of about the same area as the circle. Estimate in square centimeters the area of each of the two figures. Measure the diameter of the circle with great care, estimating to hundredths of centimeters if necessary, and record (in your notebook, not in this manual) under *Data.* See *Form of Record.* Compute the facts required to complete the tabular statement. Drop a perpendicular *BD* from the vertex of the right angle to the hypotenuse of the right triangle. Measure each of the sides of the right triangle *ABC* and measure the perpendicular *BD.* Compute the area of the triangle *ABC* by each of the two methods indicated in the tabular statement below, and compare results; account for any discrepancy. Compute the length of the side *AC* from the formula $\overline{AC}^2 = \overline{AB}^2 + \overline{BC}^2$ and compare the result with the length of the side *AC* as obtained by direct measurement; account for any discrepancy. Report.



(*Form of Record*)

STUDY OF A CIRCLE AND A TRIANGLE

CIRCUMFERENCE; AREA

CIRCLE

*Data*

Diameter (D) ........................................ cm.
$\pi = 3.14$

*Computations*

Circumference, $\pi$D ........................................ cm.
Area, $\pi R^2$ ........................................ sq. cm.
Area, estimated ........................................ sq. cm.

TRIANGLE

*Data*

Side *AB* ........................................ cm.
Side *BC* ........................................ cm.
Side *AC* ........................................ cm.
Perpendicular *BD* ........................................ cm.

*Computations*

Area, $\frac{AB \times BC}{2}$ ........................................ sq. cm.
Area, $\frac{AC \times BD}{2}$ ........................................ sq. cm.
Area, estimated ........................................ sq. cm.
Side *AC* ........................................ cm.

#### PROBLEM

A 2½-inch washer has a square hole, ¾ in. wide, cut in it; the area of the hole is what per cent of the area of the washer?

#### TOPICS FOR FURTHER STUDY AND INVESTIGATION

Sizes of steam pipe, water pipe, furnace pipe, stove pipe, and drainage pipe in common use; consult catalogues and the school engineer. With a pair of calipers measure the internal diameter of as many samples of pipe as you can find in the laboratory; compute the area of the cross section of at least two of these pipes, and report.

## 3. STUDY OF A CYLINDER

### VOLUME, DENSITY

**Apparatus.** A wooden cylinder, about 2 in. in diameter and 4 in. long; metric rule; platform balance; weights.

#### EXERCISE

Determine the diameter of the cylinder and its height in centimeters with the greatest of care, measuring each dimension in several places and taking the average, if necessary. Find the weight of the cylinder in grams. Record under *Data.* Compute the facts required in the table, making use of the formulæ there given, and record.

*Definition.* Density = mass per unit of volume; that is, number of pounds in a cubic foot, ounces in a cubic inch, grams in a cubic centimeter, etc.

In this exercise you are asked to find the number of grams in a cubic centimeter of the material employed; that is, the metric density.

Does the density of an object depend upon its size? Upon what does it depend?

(*Form of Record*)

STUDY OF A CYLINDER

VOLUME, DENSITY

*Data*

Diameter of base (D) .................................................... cm.
Height (H) .................................................... cm.
Weight (W) .................................................... g.

(Sketch) *Computations*

Radius of base (R) .................................................... cm.
Volume $\pi R^2 H$ .................................................... cc.
$\pi = 3.14$
Density $\frac{\text{Wt.}}{\text{Vol.}}$ .................................................... g. per cc.

Cylinder No. .................................... Material ....................................

#### PROBLEMS

**1.** The standpipe of a certain municipal water system, in the form of a cylinder with a circular cross-section, is 50 ft. in diameter and 30 ft. high. Required the capacity in cubic feet, in gallons, and the weight of the contents in tons.

NOTE. 1 cu. ft. = 7.48 gal.; 1 cu. ft. of water = 62.5 lb.

**2.** A hot-air furnace pipe is 8 in. in diameter. The hot air passes through it at the rate of 300 ft. per minute. Required the volume of air in cubic feet per minute, delivered by the pipe.

**3.** Design a cylindrical tank that shall hold 500 gallons of water, stating the diameter and height of the tank, and presenting a sketch, drawn to scale, of the same.

### TOPICS FOR FURTHER STUDY AND INVESTIGATION

Compute the capacity in cubic centimeters of some cylindrical vessel to be found in the laboratory. Verify by emptying the dishful of water into a glass graduate, and report.

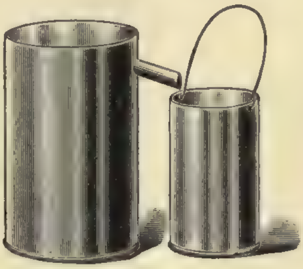
Make the necessary measurements and compute approximately, in cubic feet and in gallons, the capacity of the hot-water tank in your kitchen or of some other cylindrical tank to which you have access.

## 4. STUDY OF AN IRREGULAR SOLID

### VOLUME, DENSITY

**Apparatus.** Overflow can; catch bucket; platform balance; weights; lump of brimstone, coal, or other irregular solid; thread.

### EXERCISE



Weigh the solid. Weigh the bucket empty and dry. Place the bucket under the spout of the overflow can. Pour water into the can until it runs out at the spout. When the water has stopped running, remove the bucket; empty it, wipe dry, and replace beneath the spout, taking great pains not to jar or otherwise disturb the can of water. Tie a thread about the solid and lower it steadily into the can of water, letting it come to rest finally upon the bottom of the vessel, the displaced water meantime overflowing into the bucket. When the water has stopped running out, remove the bucket and once more weigh it with the displaced water.

Copy the Form of Record below and complete.

(*Form of Record*)

STUDY OF AN IRREGULAR SOLID

VOLUME, DENSITY

*Data*

Weight of solid .................................................. g.
Weight of bucket .................................................. g.
Weight of bucket and overflow .................................................. g.

*Computations*

Weight of displaced water .................................................. g.
Volume of solid[1] .................................................. cc.
Density .................................................. g. per cc.

To find the density in pounds per cubic foot multiply the density in grams per cubic centimeter by 62.5. Why?

### PROBLEMS

**1.** Calculate the weight of an average oak plank, 10 ft. long, 12 in. wide, and 2 in. thick. What would be the weight of an average white-pine plank of the same dimensions? See Appendix for Table of Densities.

**2.** What is the approximate weight of a cedar chest with lid, whose outside dimensions are 4 ft. × 18 in. × 10 in., and whose thickness is 1 in.?

**3.** How many bricks to a hundred pounds weight, dimensions $7\frac{3}{4}$ in. × $3\frac{1}{4}$ in. × $2\frac{1}{4}$ in.? (Density, 129.5 lb. per cu. ft.)

**4.** How many tons of coal dust would a bin 6 ft. × 4 ft. × 4 ft. hold? (Density, 94 lb. per cu. ft.)

**5.** What is the approximate weight of a concrete cylindrical basin whose outside dimensions are 3 ft. (depth) × 4 ft.; thickness of shell, 2 in.? (Density, 125 lb. per cu. ft.)

**6.** Compute the weight in tons of some brick wall whose dimensions you can easily obtain.

**7.** A mass of sand weighs 250 g. It is dropped into a cylindrical graduate containing 100 cc. of water. The water rises to the 175 cc. mark. What is the volume of the sand? What is its density?

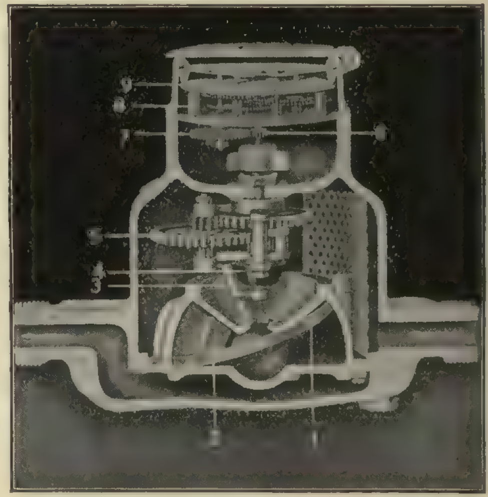
---

[1] 1 cc. water weighs 1 g.

# 5. STUDY OF A WATER METER

## TEST FOR ACCURACY

**Apparatus.** A water meter. The cut shows a vertical section of one of the latest models of the so-called disk type of water meters. The parts are numbered as follows:

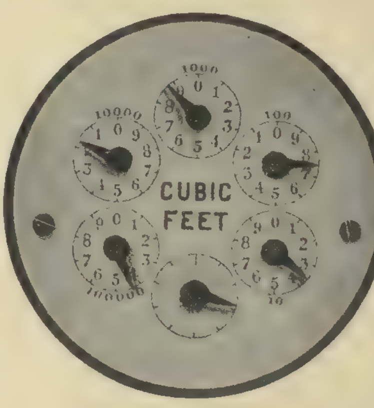


*1*, hard-rubber disk — *piston*
*2*, partition in piston chamber
*3*, piston spindle
*4*, spindle guide
*5*, intermediate train
*6*, intermediate train gear
*7*, dial train gear
*8*, dial train
*9*, dial

Such a piece of apparatus will prove a useful adjunct to any laboratory. It may be installed in the demonstration table and used to measure all the water flowing through the faucet into the pneumatic sink, or a hose connection may be attached at either side and the apparatus moved from point to point in the laboratory, as preferred.

### INTRODUCTION

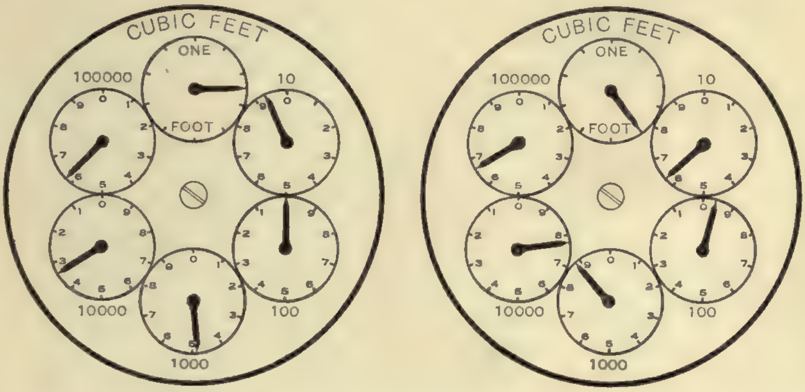
A water meter in place is in reality a water motor so fixed in a water pipe as to be set in motion by the stream of water passing through the apparatus when the pipe is open, and in turn to impart its motion, through a chain of wheels, to a series of pointers attached to a dial graduated in cubic feet. By noting the position of these pointers one can very easily determine how many cubic feet of water have passed through the meter, and hence out of the pipe, during the interval between any two successive readings of the meter. In the type of meter illustrated above, the disk (1) does not actually revolve, but is given a peculiar wabbling motion by the running water; this causes the spindle (3) to revolve about the spindle guide (4) and thus to turn the crank belonging to the intermediate train (5). At the same time the disk, by reason of its peculiar motion, allows only a fixed amount of water to pass through at each revolution of the spindle, and thus the machine actually measures out the water used.



### THE READING OF THE METER

Beginning with the circle having the largest number attached (100,000 in the illustration), record the figure just passed by the pointer, remembering always that the hand, or pointer, is moving in the direction of the increasing numbers — from the smaller to the larger; place to the right of this the corresponding figure found upon the second circle (here marked 10,000); do the same with the next circle, and so on until all the circles with figures have been read. The number thus recorded will be the reading sought. The correct reading of the dial here shown is 41,873 cu. ft.

When the pointer in any circle stands exactly over a given figure, or even very nearly so, there may be some doubt, owing to the possibility of the meter's being a little out of adjustment, as to whether the figure thus indicated is to be recorded or the one before it. In this case look at the circle next lower in number, and if the pointer in that circle is at 0 or has passed the 0 mark, then record the figure indicated by the higher circle; if not, the next lower figure. The circle without figures graduated to tenths of a cubic foot is used only for close testing by inspectors. In all ordinary readings it is to be disregarded.



Record the two readings shown in the illustration; the first reading is 63,499. Calculate the amount of water used from the time of one position of the pointers to that of the other, and the cost of the same at $1.20 per thousand cubic feet.

Read the water meter at your home at two different times, preferably a week or two apart, and calculate as above the amount of water consumed, with its cost.

### EXERCISE

*Object.* To test the accuracy of a water meter.

*Method.* Run the water from a faucet through the meter into a rectangular tank of some sort (the pneumatic sink found in most demonstration tables is admirable for this purpose) until the pointer belonging to the circle without figures (usually marked "one foot") makes one or more complete revolutions — the more the better. Counting each revolution of the pointer as one cubic foot, record the number of cubic feet now in the tank, as indicated by the meter. Record the initial and final readings of the entire dial for practice in reading the meter.

Measure the length and breadth of the tank upon the inside and the depth of water. From this data calculate the number of cubic feet of water actually delivered by the meter.

If the results do not agree, find the difference between them. This difference is what per cent of the volume arrived at by actual measurement of the tank? Record this as the error of the meter examined. Call the meter "slow" if it registers too little, "fast" if it registers too much. Make several trials, using large and small streams to show the behavior of the meter under widely varying conditions.

A more accurate test may be made, if desired, by catching the water in a bucket, weighing it, and computing the error of the meter from the fact that one cubic foot of water, as indicated by the meter, should weigh 62.5 lb. Your home meter may be tested in place by the same method.

(*Form of Record*)

### STUDY OF A WATER METER

#### TEST FOR ACCURACY

*Meter readings*

Initial reading..........................................................

Final reading..........................................................

*Volume of water indicated*.......................................... cu. ft.

*Dimensions of tank*

Length.......................................................... ft.

Breadth.......................................................... ft.

Depth of water.......................................................... ft.

*Volume of water delivered*.......................................... cu. ft.

*Error of meter*

Meter, fast, slow.......................................................... per cent

## TOPICS FOR FURTHER STUDY AND INVESTIGATION

Make a copy of the form found upon the next page, — Report upon Meter Readings, — blank dials and all. Read the meters — water, gas, and electric — at your own home or at your chum's home, upon two separate occasions, preferably a month apart; sketch in the dial hands upon your blank precisely as they appear at the time of reading, as a check upon your record. Finally, fill in the entire blank and report to the instructor, taking pains to consider, *first*, if the results appear to be *reasonable*.

See Study of a Gas Stove for suggestions upon the reading of a gas meter.

Make a study of the amount of water wasted per day, (1) through a leaky faucet, (2) in running off the water to cool it. This can be done easily by catching the water in a bucket, measuring it, and computing the cost. Try it at home. Note that a pint of water weighs 1 lb.

Packing a faucet.

Cost of filling a bathtub; of watering your lawn.

Number of gallons in a bucket of water.

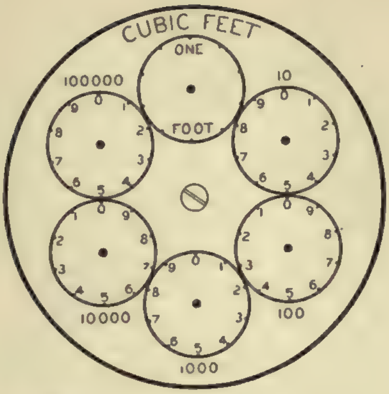
Consumption of water, in gallons, per year by an average family in the town; by your own family; by the entire town.

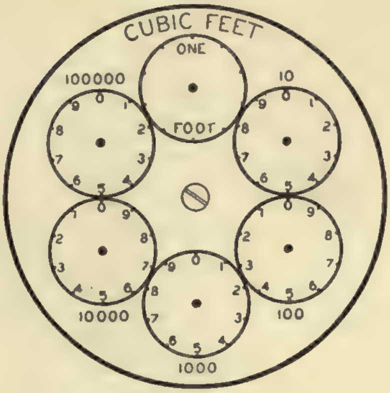
Source of the municipal water supply.

Regulations of the Water Board.

# REPORT UPON METER READINGS

## WATER





1. Date ______________________

Reading ______________________

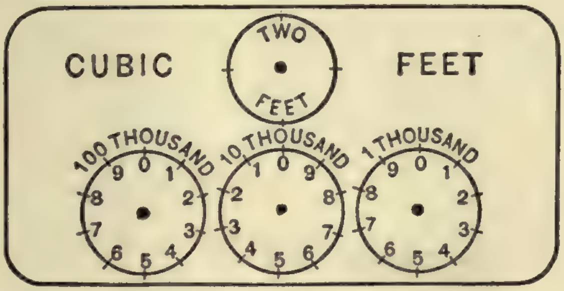
2. Date ______________________

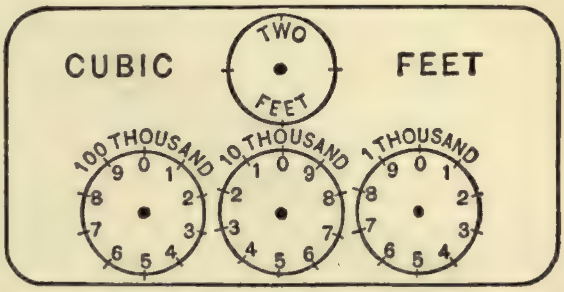
Reading ______________________

Water consumed ______________________ cu. ft.

Cost at $ __________ per 1000 cu. ft. . . $ ______________

## GAS





1. Date ______________________

Reading ______________________

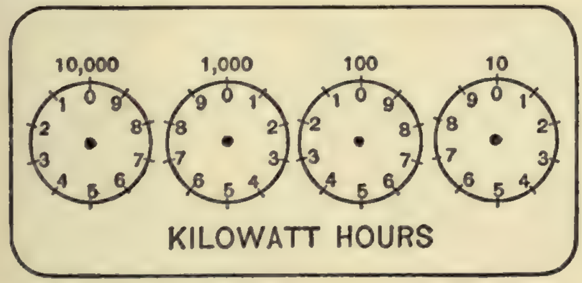
2. Date ______________________

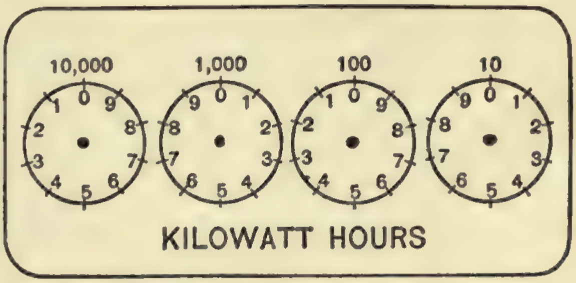
Reading ______________________

Gas consumed ______________________ cu. ft.

Cost at $ __________ per 1000 cu. ft. . . $ ______________

## ELECTRICITY





1. Date ______________________

Reading ______________________

2. Date ______________________

Reading ______________________

Electricity consumed ______________________ kw. h.

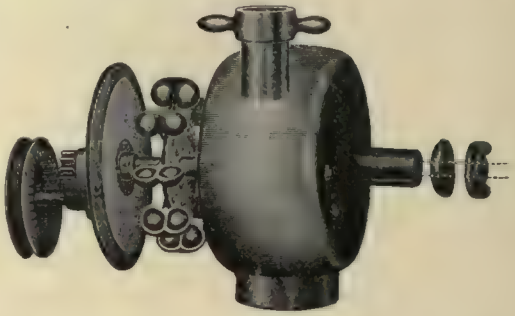
Cost at __________ per kilowatt hour . . $ ______________

______________________ Observer

## 6. STUDY OF A WATER MOTOR

### HORSE POWER: COST PER HOUR

**Apparatus.** A water motor (the larger the better) arranged to be attached to the faucet at the sink. The model shown, dissected, in the figure is provided with an auxiliary shaft connected to the main shaft by means of a reducing gear; this gives high power at low speed to the grooved pulley attached, while the motor itself is running all the while at its normal rate. Speed counter; spring balance (64 oz.); set of weights; pressure gauge; supply of small, hard cord.



### INTRODUCTION

Work is the action of a force in the production of motion against resistance. Is a man holding a heavy weight in his outstretched hand doing any work in the scientific sense? Why?

The amount of work accomplished by a machine of any kind is usually reckoned in foot pounds or kilogram-meters.

A foot pound is the amount of work done in overcoming a resistance equivalent to the weight of one pound through a distance of one foot. Work done, in foot pounds, is determined by multiplying together the resistance in pounds and the distance in feet. What is a kilogram-meter?

How much work is done in lifting 250 lb. 56 ft.? 60 kg. 2.7 m.?

The power required to accomplish a given amount of work depends upon the time in which the work is to be done. To do 2000 ft.-lb. of work in one minute, for instance, requires ten times as much power as it would to do the same amount of work in ten minutes. A horse power, as determined by James Watt in 1790, is reckoned at 33,000 ft.-lb. per minute, or 550 ft.-lb. per second.

How much horse power would be required to drive a motor car at the rate of 44 ft. a second against a resistance of 100 lb.?

What must be the horse power of an engine that is to raise 5000 gal. of water (42,000 lb.) per hour to a height of 50 ft.?

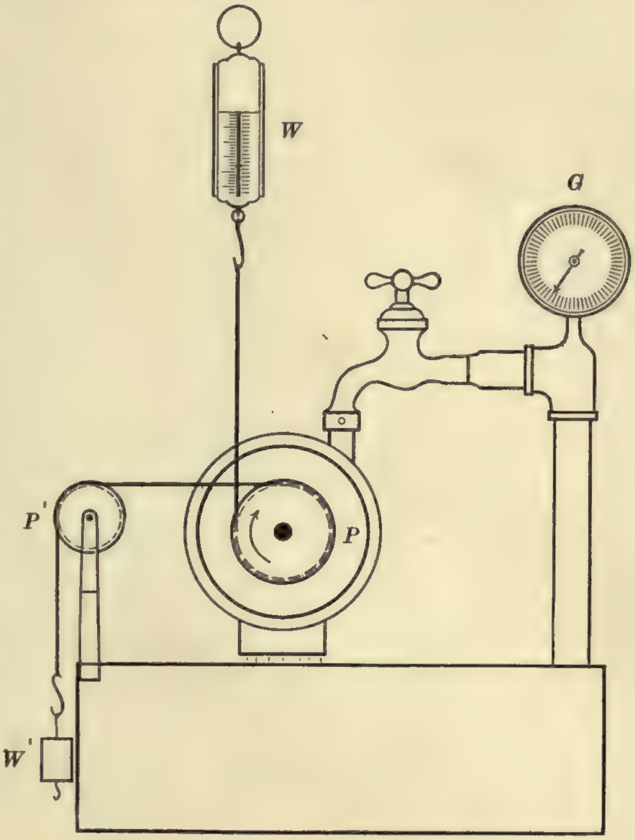
To determine the horse power of a motor of any sort we must first find out in some way the amount of work, in foot pounds, that the motor is capable of doing per minute, and then divide the result by 33,000. The kind of work done by the motor in determining its horse power is, of course, immaterial, provided always that it can be readily expressed in foot pounds. In practice it usually consists in overcoming through a given distance the resistance offered by some kind of brake applied to the flywheel or to a large pulley secured to the same shaft. Horse power so determined is often called brake horse power.

The device made use of in this exercise consists of a simple rope brake in the form of a cord (see figure on next page) encircling the grooved driving pulley ($P$), attached at one end to the hook of the balance ($W$) and at the other, over a fixed ball-bearing pulley ($P'$), to an S-hook carrying a weight ($W'$). With the motor running steadily in the direction indicated by the arrow, the pull upon the balance, expressed in pounds, will be found to be less than the weight ($W'$). The difference ($W' - W$) represents the load carried by the motor. The load, in pounds, multiplied by the circumference of the driving pulley ($P$), in feet, gives the work done in foot pounds per revolution, since the load is carried, through friction, completely around the circumference at each revolution of the pulley. The work done per revolution, multiplied by the number of revolutions per minute, gives the work done in foot pounds per minute. What next, to find the horse power?

# EXERCISE

*Object.* To determine the horse power of a given water motor when running at its most effective speed under the water pressure available in the laboratory.

*Method.* Connect up the apparatus as in the sketch. The pressure gauge *G* can be inserted in the supply pipe by means of a reducing T and will be found extremely useful as a permanent fixture. Its indications during the running of the motor have a meaning only when the faucet is wide open. Turn on the water at full head. Increase the load by substituting heavier weights at *W′* until the motor, running steadily at a fair rate of speed, appears to be hard at work. Determine the number of revolutions per minute of the driving pulley by means of the speed counter. At the same time note the average reading of the spring balance in pounds and the average reading of the pressure gauge in pounds per square inch. Note the mass of the suspended weights in pounds. Make several trials under widely varying loads. Measure the diameter of the driving pulley inside the groove by use of a pair of calipers, and compute the circumference in feet.



Copy the *Form of Record.*

Complete the tabular statement and report.

To find the cost per hour for water consumed, measure the water running through the motor in cubic feet (1 cu. ft. = 62.5 lb.) per minute and compute charges at the regular water rates.

(*Form of Record*)

## STUDY OF A WATER MOTOR

### Horse Power: Cost per Hour

(Sketch)

| | 1 | 2 | 3 | |
|---|---|---|---|---|
| *Data* | | | | |
| Revolutions per minute | | | | |
| Balance reading | | | | lb. (av.) |
| Pressure gauge | | | | lb. per sq. in. (av.) |
| Suspended weight | | | | lb. |
| Diameter of pulley | | | | in. |
| Water-consumption | | | | lb. per min. |
| *Computations* | | | | |
| Circumference of pulley | | | | ft. |
| Load | | | | lb. |
| Work done per minute | | | | ft.-lb. |
| *Conclusions* | | | | |
| Horse power | | | | |
| Cost | | | | c. per hr. |

## PROBLEMS

**1.** How much work is done in foot pounds in raising your own weight from the ground to the upper floor of the high-school building? If you can do this work in one minute by running up the stairs, how much horse power is represented during the effort?

**2.** A standpipe 100 ft. high holds, when full, 30,000 cu. ft. of water. What must be the horse power of the pump that will fill it in one hour if the pipe enters at the top?

**3.** What must be the horse power of an automobile weighing 4000 lb. if it is to carry seven persons, weighing 150 lb. each, from the foot of a hill 365 ft. high to the top in two minutes, no allowance being made for friction or the resistance of the air?

**4.** What is the horse power of a locomotive if it draws a train weighing 1000 tons at the rate of 30 miles an hour, and the total resistance to motion is 25 lb. per ton?

## TOPICS FOR FURTHER STUDY AND INVESTIGATION

### Efficiency of a Water Motor

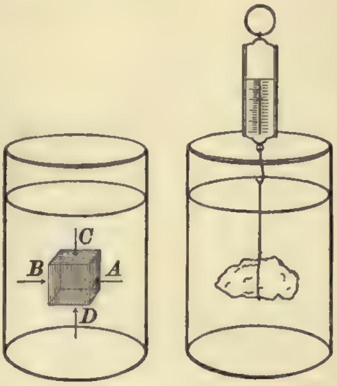
*Hint.* Efficiency $= \frac{\text{output}}{\text{input}} = \frac{\text{horse power of the motor}}{\text{horse power of the running water}}$. Horse power of the running water = water consumption in pounds per minute × the effective head ÷ 33,000. The effective head = 2.3 × the water pressure in pounds per square inch (since a pressure of 1 lb. per square inch is equivalent to a column of water 2.3 ft. in height).

# 7. STUDY OF A LIQUID

## BUOYANCY OF WATER

**Apparatus.** Jar of water; block of wood; lump of coal or other solid that sinks in water; water-proofed wooden cylinder or other solid that floats in water; spring balance; overflow can and catch bucket; thread.

### INTRODUCTION



Drop the wooden block carefully into the jar of water. Push it steadily downwards into the water with the fingers, until it touches the bottom of the jar. Note the apparent up-push — buoyant action of the water upon the block. Does the buoyancy increase as the block descends or not? Make a careful statement upon this point, covering these two cases: (1) when the block is partly out of water; (2) when it is entirely submerged. Explain.

By means of a thread attach the lump of coal or other solid to the hook of the spring balance in such a manner that the solid may hang in the air some six inches below the balance when the latter is suspended by the ring held between the thumb and forefinger of the right hand, and determine its exact weight in grams. Lower the solid still suspended from the balance slowly into the water until it is entirely covered. Note the reading of the balance. Is there any evidence of a buoyant action of the water upon the solid? Measurement in grams?

No one has the least idea when the discovery of this buoyant action of water was first made by man, — probably ages ago, — but the phenomenon was first carefully studied by the great philosopher and mathematician Archimedes in 240 B.C., and to him we are indebted for the following law, known to-day the world around as *Archimedes' Principle: A body immersed in a fluid is buoyed up by a force equal to the weight of the fluid displaced*, and its corollary: *The weight of a floating body is equal to the weight of the fluid displaced.* To illustrate the truth of this important principle is the object of the exercise.

NOTE. One must not be surprised or disappointed if the results obtained in this exercise are not in precise accord with the principle as above stated. To discover a new principle in nature, or even to prove to one's own satisfaction the truth or falsity of a great law already enunciated, is by no means an easy task.

Work as carefully as you know how; study the method, the apparatus, the results, and see if you can account for any discrepancy. The instructor will help you at this point.

### EXERCISE

*Object.* To test the principle of Archimedes with reference to water. In two parts: (1) as applied to a body that sinks in water; (2) as applied to a body that floats in water.

*Method.* 1. *Sinking solid.* Weigh the solid; then, suspending the solid by a thread from the hook of the spring balance, weigh it immersed in water; by means of the overflow can, find the weight of the water displaced (see Study of an Irregular Solid); calculate the buoyant action of the water upon the solid. Compare result with the principle of Archimedes.

2. *Floating solid.* Weigh the solid; find the weight of the water displaced when the solid is quietly floating in the water of the overflow can; test the principle.

What would be the effect upon the floating solid if a small weight were placed upon the top of it? How much more water would the solid displace? Try it and see.

(*Form of Record*)

## STUDY OF A LIQUID: BUOYANCY OF WATER

### Archimedes' Principle

*Data*

1. Weight of sinking solid.......... g.
   Weight of solid immersed in water.......... g.
   Weight of empty bucket.......... g.
   Weight of bucket and overflow.......... g.
2. Weight of floating solid.......... g.
   Weight of bucket.......... g.
   Weight of bucket and overflow.......... g.

*Computations*

1. Lifting effect of the water upon the solid immersed in it; apparent loss of weight; buoyancy.......... g.
   Weight of water displaced by the solid.......... g.
2. Weight of floating solid.......... g.
   Weight of displaced water.......... g.

*Conclusion*

## PROBLEMS

**1.** How much less will 1 cc. of any material weigh under water than in air? How much less will 1 cu. ft. of any substance weigh under water than in air?

**2.** A raft is 30 ft. long, 20 ft. wide, and 5 ft. thick. It floats with its upper surface 2 ft. above the water. What is the weight of the raft?

**3.** What would be the net uplift of a cubic foot of pine if totally submerged in water? of a cubic foot of cork? See Appendix for Table of Densities.

**4.** Calculate the lifting power of a chestnut log of length 10 ft. and diameter 8 in. when totally submerged in water.

**5.** A metal cask displacing 8 cu. ft. is immersed in water. The cask and confined air together weigh 100 lb. What is the net uplift of the combination in pounds? Would the lifting power be increased or decreased if the air were removed from the inside? if the air were replaced by cork? Why?

## TOPICS FOR FURTHER STUDY AND INVESTIGATION

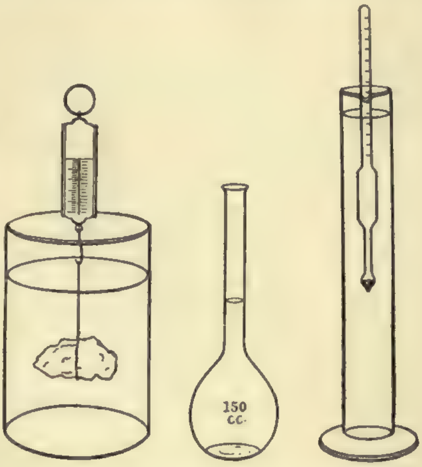
Floating wharves, bridges, and dry docks; floats in water tanks.
Use of pontoons for raising sunken ships.
Use of the air bladder in fishes.
Hot-air balloons; gas balloons; submarines.
Displacement of canoes and rowboats; of battleships and ocean liners.
Winds and ocean currents.

# 8. STUDY OF A LIQUID

## SPECIFIC GRAVITY; SEA WATER

**Apparatus.** A quantity of sea water or a saturated solution of salt and water, gasoline, or milk; 150 cc. flask; piece of glass, lump of coal, or other sinking solid; a small jar; platform balance with metric weights; spring balance; hydrometer.

### INTRODUCTION



By the specific gravity of a substance is meant its weight as compared with the weight of the same volume of some other substance taken as a standard. In dealing with liquids and solids pure water is taken as the standard; gases are referred to air.

To find the specific gravity of a solid or a liquid, divide the weight of the given specimen by the weight of an equal volume of water.

The specific gravity of substances heavier than water must evidently be greater than unity; of substances lighter than water, less than unity.

### EXERCISE

*Object.* To find the specific gravity of sea water, that is, to determine how the weight of the salt water in the ocean compares with the weight of an equal volume of fresh water:

*Method 1.* Weigh the flask empty. Fill it with sea water up to the 150 cc. line and weigh again. Empty the sea water back into the carboy. Fill the flask to the same line with fresh water. Weigh again. From these three weighings calculate the specific gravity of sea water.

*Method 2.* Weigh the solid in air. Weigh the solid submerged in sea water. Wipe the solid dry and weigh it submerged in fresh water. Calculate the apparent loss of weight in sea water and in fresh water, respectively. From these data find the specific gravity of sea water (see Archimedes' Principle). Explain clearly how this method squares with the definition of specific gravity as given in the introduction.

*Method 3.* Float the hydrometer in sea water and read the specific gravity directly.

*(Form of Record)*

STUDY OF A LIQUID

SPECIFIC GRAVITY: SEA WATER

1. *Data*

Weight of empty flask.................................... g.
Weight of flask and sea water.................................... g.
Weight of flask and fresh water.................................... g.

*Computations*

Weight of sea water.................................... g.
Weight of fresh water.................................... g.
Specific gravity....................................

2. *Data*

Weight of solid in air.................................... g.
Weight of solid in sea water.................................... g.
Weight of solid in fresh water.................................... g.

*Computations*

Apparent loss of weight in sea water (buoyancy).................................... g.
Apparent loss of weight in fresh water (buoyancy).................................... g.
Specific gravity....................................

3. *Hydrometer Reading*

Specific gravity........ ....... ........................... ..... .................... ...............................................

*Conclusion*

**Specific gravity of sea water (average of results)**........................................................

### PROBLEMS

1. Calculate the weight of a cubic foot of sea water (specific gravity, 1.026) from the fact that a cubic foot of fresh water weighs 62.5 lb.

2. The battleship *Connecticut* displaces 16,000 tons of sea water when loaded. How many cubic feet of water does the ship displace? How many tons does the ship with its contents weigh?

3. It is desired to build a canoe that shall carry two persons weighing 150 lb. apiece. If the canoe alone is to weigh 75 lb., how many cubic feet of sea water must it displace when loaded? How many cubic feet when empty?

4. How much pressure in pounds per square inch is exerted by the ocean upon an article resting upon the bottom at a depth of 100 ft. (pressure in fresh water = .434 lb. per square inch for each foot of depth.)? at a depth of 2 miles?

5. How far beneath the surface of the ocean must one descend to experience a pressure of 150 lb. per square inch?

6. Compute the weight of a gallon of kerosene (specific gravity, .79) from the fact that a pint of water weighs a pound.

### TOPICS FOR FURTHER STUDY AND INVESTIGATION

Specific gravity of gasoline; of milk; of mercury.

Board of Health regulations concerning the sale of milk.

Various forms of hydrometers.

Specific gravity of a solid that sinks in water. *Suggestion:* Weigh the solid in air. Weigh the solid immersed in water. Find the loss of weight. Divide the weight in air by the loss of weight in water. Explain.

Specific gravity of a solid that floats in water.

## 9. STUDY OF A LIFE PRESERVER

### LIFTING POWER; SPECIFIC GRAVITY

**Apparatus.** A standard life preserver; parts of another made by cutting through the canvas cover that binds the blocks together and separating them; sinker heavy enough to submerge a single block in water; 64 oz. spring balance; small tank, tub, or pneumatic sink, filled with water.

The blocks should be numbered separately and distributed to the class.

NOTE. To pass inspection by the United States government all life preservers of the type here shown must be at least 52 in. long, contain 5½ lb. of good cork, and be capable of sustaining continuously for 24 hr. a "downward gravitational pull" of not less than 20 lb.

### INTRODUCTION

It is a fact worth knowing that the amount of effort required to keep a person afloat in the water depends largely upon how much of his body he is willing to keep under water. From a series of experiments conducted at the Brookline swimming pool it appears that an average boy of high-school age, falling into the water fully dressed, requires an extra support on the part of a rescuer of 5 lb. if kept on his back with his nose and mouth out, 12 lb. if in an upright position with his head out, and 26 lb. with his head and arms out. The lesson is obvious.

### EXERCISE

*Object.* To determine the lifting power of a standard life preserver when entirely submerged in water, and its specific gravity.

*Method.* Weigh one of the blocks. Weigh the sinker in water. Tie the sinker to the block and weigh both together submerged in water. Compute the lifting power of the block. Count the number of blocks in the standard life preserver and compute the probable lifting power of the whole. To what is this lifting power due?

Find the total buoyant effect of the water upon the block by adding the weight of the block to its lifting power. This gives at once, by Archimedes' Principle, the weight of the water displaced by the block. Compute the specific gravity of the block, and approximately of the life preserver as well, by finding the ratio between the weight of the block and the weight of the displaced water.

Examine a partially dissected life preserver and note the materials of which it is made. Try one on and see how it is intended to be adjusted to the body.

Make up your own form of record, including the combined results of the class, and report.

### PROBLEMS

**1.** If it requires 13 lb. to sustain a boy in the water with his head out, how many boys in this position would the life preserver used in this exercise sustain, if it were entirely submerged?

**2.** If a boy weighs 130 lb., and it requires 5 lb. to keep him from sinking when entirely under water, what is his volume in cubic feet? What is his specific gravity? How many cubic feet of cork will be required to keep him from sinking?

### TOPICS FOR FURTHER STUDY AND INVESTIGATION

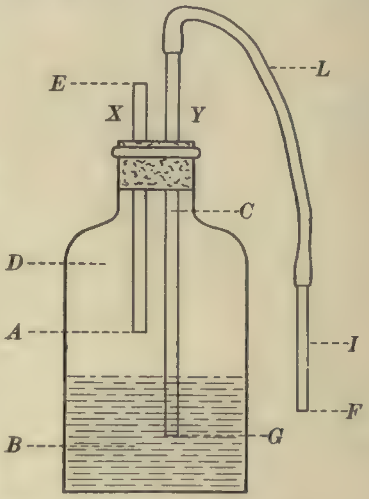
Various types of life preservers.

Law requiring a supply of life preservers upon passenger vessels: their location and use.

# 10. STUDY OF A FLUID

## AIR PRESSURE; WATER PRESSURE

**Apparatus.** A pint bottle partly filled with water and fitted with a rubber stopper carrying two glass pipes, one ($X$) extending to a point just above the water, the other ($Y$) extending down into the water. A short piece of rubber tubing ($L$) tipped with a bit of glass tubing ($I$) is slipped over the upper end of $Y$. (This may be transferred to the upper end of $X$ when necessary.) A small jar or tumbler half full of water.



### INTRODUCTION

This exercise, if properly performed, cannot fail to bring out some of the more important principles made use of in hydrostatics and pneumatics, and to impress them upon the mind of the pupil.

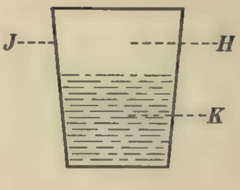
A large number of glass tips ($I$) should be provided, so that each pupil may have one for his individual use, or the tubes may be sterilized after use by boiling in water.

The exercise may be written up in the form of a narrative or be made the basis of an oral quiz.

The student should distinguish carefully between what is actually observed (that is, noted by the senses) and what is simply inferred (that is, arrived at by a process of reasoning). The questions to be answered in each case are these: What happened? Why did it happen? All statements should be made with the precision of an original exercise in geometry as follows:

*Observations:* 1. (*a*) Bubbles appeared at $G$ and rose through $B$ into $D$. (*b*) Water rose in $Y$, finally coming to rest at a fixed point, etc.

*Inferences:* 1. (*a*) Air pressure in $Y$ must have been greater than water pressure at $G$ and air pressure in $D$. Bubbles of air are lighter than the volume of water which they displace (Archimedes' Principle). (*b*) Air pressure in $D$ balanced pressure due to water column in $Y$ and air pressure at $F$, etc.



### EXERCISE

*Object.* To study the action of a column of water under varying conditions of air pressure, and to account for it.

*Method.* 1. (*a*) Close $X$ by placing the end of one finger over $E$. Apply the lips at $F$ and gently force air into $Y$. (*b*) Relieve the pressure at $F$, keeping $X$ still closed. (*c*) Release $X$. Observations? Inferences?

2. (*a*) Force air gently in at $X$, transferring the rubber pipe to $X$ for this purpose, and close $X$ by pinching the rubber tube while the pressure is still on. (*b*) Release $X$. Observations? Inferences?

3. (*a*) Apply the lips at $F$ and gently exhaust the air from $X$, closing $X$ by pinching the rubber pipe while the suction is still on. (*b*) Release $X$. Observations? Inferences?

4. (*a*) Do the same with pipe $Y$. (*b*) Try exhausting air from $Y$ while $X$ is closed. (*c*) Release $X$ while the suction is still on. Observations? Inferences?

5. Place the tumbler and the bottle side by side. Allow the open end of $I$ (the rubber pipe being attached to $Y$, as in the illustration) to fall into $J$ until $F$ lies below the surface of $K$. (*a*) Force air in at $E$. Explain fully. (*b*) Exhaust air at $E$ until a small portion of $K$ runs over into $B$. Now raise $J$ until the upper surface of $K$ is at a higher level than the upper surface of $B$; lower $J$. Explain fully. (*c*) Empty $Y$. Explain method.

6. Pour water into *D* until the bottle is two thirds full; remove the rubber pipe entirely. (*a*) Close *Y* by placing one finger over the end of the pipe. Invert the bottle over *J.* (*b*) Open and close *Y* alternately. Explain fully.

7. Empty *B*; replace the rubber pipe upon *Y.* Close *X* with the finger. Exhaust heavily from *Y* by applying the lips at *F.* Pinch *L* while the suction is still on, and, keeping *X* still closed, place *F* under water, *K*, and release *L.* Explain fully.

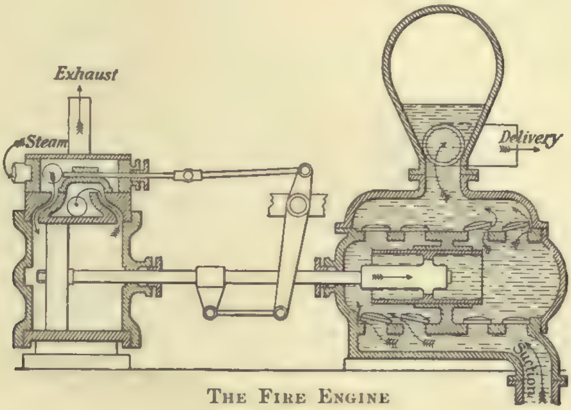
8. Upon the hypothesis that a column of water one inch in height represents a pressure of .036 lb. to the square inch, estimate the difference of pressure produced in as many of the above experiments as possible.

### TOPICS FOR FURTHER STUDY AND INVESTIGATION

Action of a siphon; an air pump; a bicycle pump; an ordinary lift pump; a force pump with air chamber; a vacuum cleaner; a gas meter; a soda fountain; pneumatic tubes for mail delivery; the lungs in breathing.

Measurement of gas pressure by a U-tube water manometer.

The fire-engine pump.



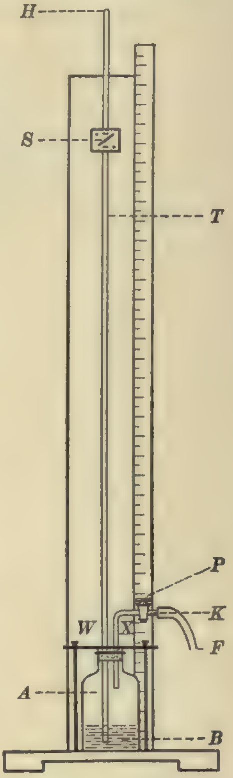
THE FIRE ENGINE

## 11. STUDY OF A BAROMETER

### FUNDAMENTAL PRINCIPLES

**Apparatus.** A wide-mouthed 8-oz. bottle, containing about 2 lb. of distilled mercury, fitted with a rubber stopper carrying two glass pipes. One of these pipes, *W* (see illustration), a piece of barometer tubing 38 in. in length, having a stopcock, *S*, near one end, extends down into the mercury and is open at both ends. The other, *X*, also provided with a stopcock, *P*, reaches down to a point just above the surface of the mercury and is bent at right angles above the rubber stopper. The stopper is held in place by a yoke of brass securely bolted to the simple frame upon which the whole is mounted. A yardstick secured in an upright position parallel to the barometer tube serves to measure the height of the mercury at any time in the pipe *W*.

A small air pump, so arranged that it may be made to exhaust or condense at will, provided with a piece of heavy rubber tubing, by means of which it may be connected at any time with *W* at *H* or with *X* at *K*.



#### EXERCISE

*Object.* To secure at first hand a knowledge of the principle upon which a barometer acts in measuring the pressure of the atmosphere.

*Method.* 1. With stopcocks *S* and *P* both open, force air steadily in at *K* until the mercury rises in *W* to a point about 20 in. above the surface of *B*. Then close *P*. Explain why the mercury rose in the pipe *W*.

If a column of water 1 in. in height represents a pressure of .036 lb. to the square inch, and mercury is 13.6 times as heavy as water, how much pressure will a column of mercury 1 in. in height represent?

Now measure the height in inches of the upper end of the mercury column in *W* above the surface of *B*, and calculate the excess of pressure in *A*.

Remove the pump and open *P*. Explain why the mercury falls.

2. Again force air steadily in at *K*, continuing the operation until the mercury column rises in *W* to a point just above the stopcock *S*. Close *S* and again remove the pump. Why does the mercury fall? Why does it not fall down to the level of *B*? What is there in pipe *W* between the upper surface of the mercury column near *T* and the stopcock *S*?

3. With *S* still closed, apply the lips at *F* and gently exhaust air from *A*; force air in at *F*. Observations? Note the sharp click as the mercury bumps against the stopcock. What does this show?

The instrument as at present arranged represents a crude barometer, that is, "pressure measurer." What are the essential parts? the nonessential?

What will be the effect upon the mercury column if the air in the room increases in pressure? if it decreases?

4. Measure the height of the mercury column in *W* above the surface of *B*,* as in 1, and calculate the pressure of the atmosphere as thus indicated in pounds per square inch.

A change in pressure of how many pounds per square inch is indicated by a fall in the barometer of 1½ in.? An increase or a decrease in pressure?

5. Open *S*. Explain why the mercury falls.

6. Apply the pump at *H* and exhaust until the mercury column in *W* stands about half as high as it did in 2 above, after the pump was removed. Close *S*.

---

* This distance is called the height of the barometer.

How high would the mercury column now stand if all of the air had been pumped out of *W*? How high does it stand? Then what fraction of the air formerly in *W* was removed by the pump?

7. Open *S* and exhaust again slowly and steadily, continuing the operation until the mercury column ceases to rise. Then close *S*. How does the height of the column now compare with that reached in 2? Ascertain the exact height of the mercury column above *B*. By comparing this with the height obtained in 2, determine what fraction of the air formerly in *W* has been removed, and thus calculate the efficiency of the pump by determining the maximum percentage of air removed by its aid.

A Bourdon combined vacuum and pressure gauge, connected in series with the above, adds greatly to the value of the exercise.

### PROBLEMS

**1.** Read the barometer in the laboratory and compute the corresponding atmospheric pressure in pounds per square inch; in grams per square centimeter; in feet of water.

NOTE. A barometer height of 76 cm., or 30 in., represents a pressure of approximately 15 lb. per square inch, 1033 g. per square centimeter, or 34 ft. depth of water. To find the corresponding facts at 73 cm., or at 29 in., take $\frac{73}{76}$, or $\frac{29}{30}$, of 15 lb., 1033 g., etc.

**2.** If the surface of one's body represents an area of 20 sq. ft., how many tons of atmospheric pressure must one sustain if the barometer reads 28 in.? Why are we not crushed by such pressures? Effect of a sudden increase in pressure? of a sudden decrease?

**3.** To what height can water be raised by a common lift pump if the barometer stands at 28 in.?

### TOPICS FOR FURTHER STUDY AND INVESTIGATION

The water hammer.
The aneroid barometer.
The barometer as a weather prophet.
The barometer as used upon an aëroplane.
Isobars and the weather bureau.
Finding the heights of mountains by the use of a barometer.

## 12. STUDY OF A FIRE EXTINGUISHER

### CONSTRUCTION; OPERATION

**Apparatus.** A fire extinguisher of the type shown in the illustration. This will probably be found in the school corridor, charged and ready for use.

### CLASS EXERCISE

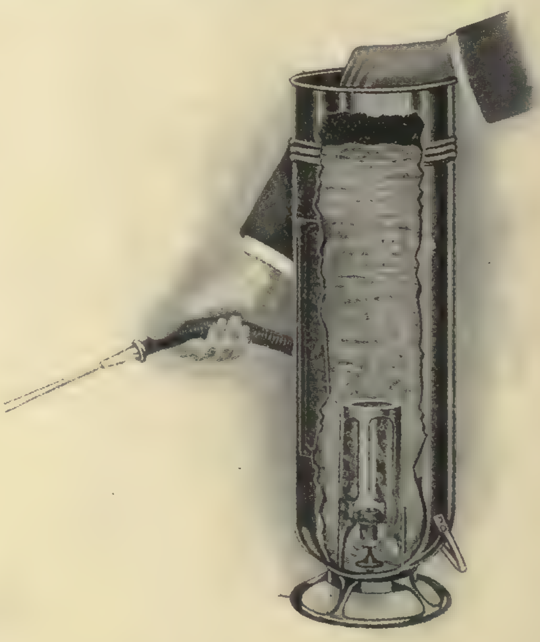
*Object.* To see how the apparatus is put together and to learn how it works.

*Method.* Unscrew the cover of the apparatus and remove it. Lift out the glass bottle with the porcelain stopper, together with the wire cage that holds it (taking care not to spill the contents or to splash any drops upon your clothing), and set it aside for further examination. Empty the contents of the body of the apparatus into a large jar, a water pail, or other receptacle. Test the liquids by placing a drop of each upon litmus paper, to determine which, if either, is acid and which is alkaline. Observations?

Add a few drops of the acid to a small quantity of the alkaline solution placed in a test tube. Plunge a lighted match into the open end of the test tube. Observations?

Sulphuric acid and baking soda in solution (the acid and the alkali of this exercise), when mixed in the right proportions, generate the gas carbon dioxide ($Co_2$) in large volumes. Carbon dioxide, being a nonsupporter of combustion, puts out a fire by smothering it, or cutting off the supply of oxygen. How does water act?

Consider now what would happen if the apparatus, in its normal condition, were suddenly inverted, as in the second figure. Explain. What precautions are to be taken in the use of the apparatus? Consult the instructor at this point.



Restore the apparatus to its original condition and, by inverting the can, discharge its contents through the hose into the back yard or upon some waste heap out of doors. How far did it throw? How high? For how many minutes did the discharge last?

Recharge the apparatus and return it to its station.

Read the article headed "Fire Extinguishers" in any good encyclopedia. Write a description of the apparatus and describe its action. Consult the latest catalogues upon the subject.

### TOPICS FOR FURTHER STUDY AND INVESTIGATION

Various kinds of fire extinguishers for home use (see advertisements in monthly magazines).

Spontaneous combustion.

First aid to the injured: burns.

Fire escapes in connection with public buildings.

The fire department in your own town.

Underwriters' rules regarding storage of gasoline, kerosene, naphtha, and explosives of all kinds.

# 13. STUDY OF A GAS

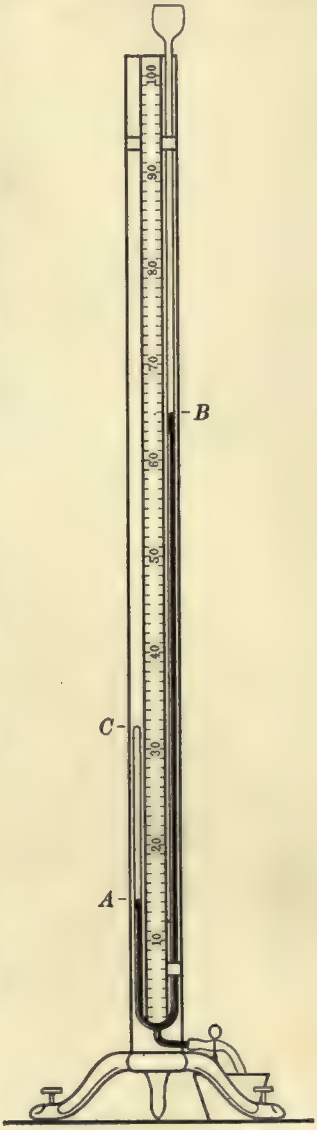
## BOYLE'S LAW

**Apparatus.** Boyle's law tube, of the usual form but with an opening at the bottom closed with a pinchcock and a *tightly fitting* rubber pipe; ½ lb. of mercury; barometer; small beaker.

### EXERCISE

*Object.* To prove that at constant temperature the product of the pressure and the volume of a given mass of gas is constant.

*Method.* Pour mercury into the tube through the funnel (slowly, to avoid air bubbles) until the liquid in the long arm reaches nearly to the top of the tube. The pressure upon the air column ($AC$) is now equal, clearly, to the pressure of the column of mercury in the long arm above the level of the point $A$, plus the pressure of the atmosphere upon the top of the mercury column at $B$. The total pressure may therefore be determined by adding these two together, provided always that both be expressed in the same units (preferably in centimeters of mercury). How is the atmospheric pressure to be obtained?



1. Read the position ($A$, $B$) of the *top* of the mercury column in each arm against the meter stick, and record. See *Form of Record.*
2. Open the pinchcock carefully and allow a small quantity of mercury (enough to drop the mercury column in the long arm about 10 cm.) to flow out into the small beaker placed at the side; then close the pinchcock. Read $A$ and $B$ as before, and record.
3. Continue in this way, reading and recording the height of the mercury in each arm at each drop of 10 cm., until you have emptied the tube.
4. Record the reading of the upper end ($C$) of the air column in the closed arm, making due allowance for the curve at the top.
5. Read the barometer and record in centimeters.
6. Complete the tabular statement.

Find the average of the products recorded under Volume × pressure. Find the greatest departure from this average. Call this the *error.* Calculate the percentage of error, using as a base the average as above determined. Finally, plot a curve, using pressures as ordinates (vertical distances) and volumes as abscissas (horizontal distances).

*(Form of Record)*

STUDY OF A GAS

BOYLE'S LAW

*Data and Computations*

| | Mercury reading $A$ | Mercury reading $B$ | Volume of air $C - A$ | Mercury pressure $B - A$ | Total pressure $H + B - A$ | Volume × pressure |
|---|---|---|---|---|---|---|
| 1 | | | | | | |
| 2 | | | | | | |
| 3 | | | | | | |

Reading of upper end of air column ($C$) = .................... cm.     Barometer reading ($H$) = .................... cm.

*Conclusion*

## PROBLEMS

**1.** Why does the air fill one's lungs when the chest is expanded? Why does the water rise in the pipe of a lift pump when the piston is raised? Why does the air rush out of a bicycle pump when the piston is suddenly pushed to the bottom of the cylinder?

**2.** A given mass of air occupies a volume of 200 cc. at a pressure of 76 cm. of mercury. What volume would it occupy at 75 cm.?

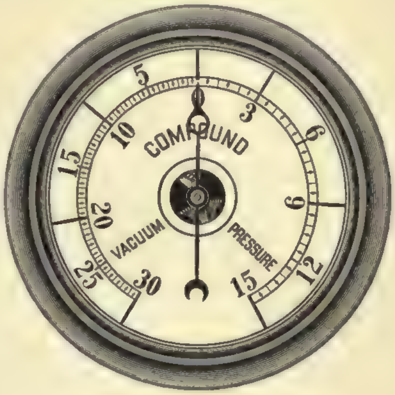
**3.** What pressure in pounds per square inch is exerted by the confined air in the air dome of a force pump if the volume of air has been compressed to $\frac{1}{3}$ of its volume at normal atmospheric pressure? To what height would a column of water in a vertical pipe be sustained by this pressure?

**4.** A bubble of air starts to ascend through the water from the bottom of a pond 20 ft. deep. If its volume at the start was 2 cc., what will be its volume just as it reaches the surface of the pond, the barometer standing at 30 in.?

## 14. STUDY OF A BOURDON GAUGE

### TEST FOR ACCURACY

**Apparatus.** The gauge to be tested. The instrument shown in the illustration is a Crosby compound vacuum-and-pressure gauge, for use upon steam, water, or air. The numbers at the right of the 0 indicate pounds per square inch; the numbers at the left of the 0 represent inches of mercury and refer to the corresponding readings of a mercury manometer upon which a difference in level of 30 in. (when produced by the exhaustion of air) may be taken to indicate a complete vacuum.



A simple stand for the support of the gauge, with a hose connection on either side (see figure below).

A U-tube manometer partly filled with mercury. An air pump arranged to exhaust or compress at will. Pressure tubing. Two pinchcocks. A brass T to fit the rubber tubing.

**Note.** Do not attempt to exhaust from a pressure gauge or to put pressure upon a vacuum gauge.

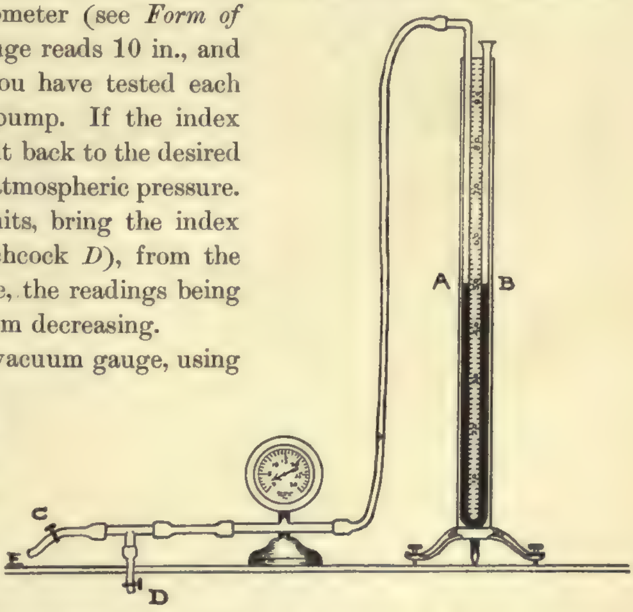
### EXERCISE

*Object.* To test the accuracy of a Bourdon gauge (vacuum or pressure) by direct comparison with a mercury column.

*Method.* The method, as outlined, refers to two separate gauges, one for vacuum and one for pressure, but the same method may be used, of course, to test the two sides of a compound gauge as well.

1. *The vacuum gauge.* Set up the apparatus as in the illustration, the pump being attached at *E*. Make sure that all the joints are tight; then secure each by binding with wire. Close pinchcock *D*; open *C*. Exhaust slowly at the pump until the gauge reads exactly 5 in. Close pinchcock *C*. Determine the difference in level between the mercury columns *A* and *B*, and record in inches beside the corresponding gauge reading, under Manometer (see *Form of Record*). Open *C*. Exhaust again until the gauge reads 10 in., and record as before. Proceed in this way until you have tested each division of the gauge up to the limit of the pump. If the index hand moves too far at any time, it may be brought back to the desired point by opening *D* and slowly admitting air at atmospheric pressure. Complete the tabular statement. If time permits, bring the index back, step by step (by the skillful use of pinchcock *D*), from the highest point reached to 0, and record once more, the readings being noted this time in the reverse order, with vacuum decreasing.

2. *The pressure gauge.* Proceed as with the vacuum gauge, using the pump arranged as a compressor, applying pressure at *E* and noting successive readings of the mercury column as the gauge index reaches the various divisions of the scale up to the limit of the manometer — 15 lb. per square inch. From the differences of level in inches compute pressures in pounds per square inch (making use of the fact that it requires a pressure of 14.7 lb. per square inch to support a column of mercury 30 in. high), and record as before. Finally, plot a curve, using gauge readings as horizontal distances and manometer readings as vertical distances.



(*Form of Record*)

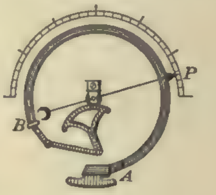
## STUDY OF A BOURDON GAUGE

### TEST FOR ACCURACY

| Vacuum Increasing | | |
|---|---|---|
| Gauge | Manometer | Error |
| | | |

## TOPICS FOR FURTHER STUDY AND INVESTIGATION

Principle of the Bourdon pressure gauge. The metal tube *AB* (see figure), of elliptical cross section, is bent nearly into a circle and is closed at the end *B*. The steam or compressed air entering at *A* tends to straighten out the tube, and the movement of the free end, communicated through a rack-and-pinion movement to the index hand *P*, registers upon a dial the amount of pressure applied. When the pressure is released, the elasticity of the tube restores the index hand to its original position.



Look up the commercial method for the testing of large gauges.

If you can borrow a gauge of sufficient capacity from the laboratory or elsewhere, measure the water pressure at your own home upstairs and downstairs, and report.

Find out what pressure is carried upon the steam boilers connected with the heating plant of your school building; upon a locomotive boiler; upon the boilers of an ocean steamer.

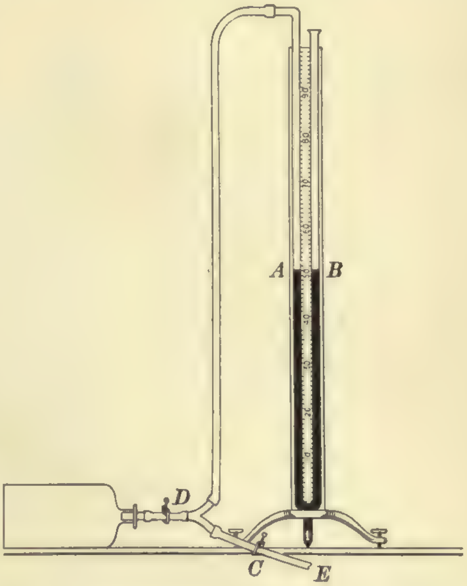
Experiment with a gauge to determine how much steady pressure in pounds per square inch and how much of a vacuum in inches of mercury you can produce by the use of your own lungs.

## 15. STUDY OF A GAS

### DENSITY OF AIR

**Apparatus.** A 2-liter glass bottle fitted with a rubber stopper pierced by a short piece of ¼-inch glass tubing; a few feet of rubber tubing, heavy enough to withstand the pressure of the atmosphere when the air is exhausted from the inside, and of a size to fit tightly over the glass tubing; two stout pinchcocks; a glass or metal Y-tube; platform balance; metric weights; air pump or aspirator; U-tube manometer partly filled with mercury.

The capacity of the bottle, determined from the number of cubic centimeters of water required to fill it, should be marked upon its side, and thereafter the bottle should be kept clean and dry.



#### EXERCISE

*Object.* To determine the weight of 1 cc. of dry air under the conditions of pressure and temperature existing in the laboratory at the time of the experiment.

*Method.* Set up the apparatus as in the illustration, the pump being attached at *E.* Make sure that all the joints are tight; this can be accomplished by the use of small quantities of vaseline applied at the junctions, between the glass and the rubber.

Exhaust slowly and steadily at the pump until the difference in level between the mercury columns *A* and *B* is as large as you can make it; then close pinchcock *C* and watch the mercury. If no leak appears, read the position of the *top* of the mercury column in each arm against the meter stick to one tenth of a centimeter, and record the difference in level as the manometer reading. Close pinchcock *D* tightly. Disconnect the bottle from the Y-tube and weigh carefully to one tenth of a gram. Then by opening the stopcock *D* without removing the bottle from the balance, allow the air to reënter the bottle, and weigh again. Record the capacity of the bottle in cubic centimeters, as marked upon the label. Read the barometer. Compute the facts required to answer the following questions: What percentage of the air originally in the bottle was removed by the pump? How many cubic centimeters? (*Suggestion:* To find the percentage of air removed, divide the reading of the manometer by the barometer reading. Explain.) How many grams of air were removed from the bottle? Find the weight of 1 cc. of air. Make up your own Form of Record, and report.

Note. To find the density of the air in ounces per cubic foot, multiply its density in grams per cubic centimeter by 62.5 and the product by 16. Explain.

#### PROBLEMS

**1.** From the average of the results obtained by the class, compute the density of the air in ounces per cubic foot. Is this quantity always the same. Why?

**2.** Find the weight of air contained in a room 40 ft. × 50 ft. × 12 ft. if 1 cu. ft. of air weighs 1.25 oz.

**3.** The volume of a balloon is 30,000 cu. ft. The bag and the car weigh 250 lb. Find the lifting power of the balloon if 1 cu. ft. of the gas used weighs .5 oz. and the surrounding air weighs 1.3 oz. per cubic foot.

**4.** What must be the volume of a balloon in cubic feet to sustain a man weighing 150 lb. in the air if the envelope of the balloon weighs 75 lb. and is filled with hydrogen gas of a density of .08 oz. per cubic foot, while the surrounding air has a density of 1.2 oz. per cubic foot? Would the balloon rise or fall if the rays of the sun suddenly fell upon it? Why is a balloon before ascension only partly filled with gas?

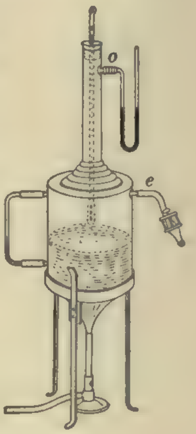
## 16. STUDY OF A MERCURY THERMOMETER

### FIXED POINTS: TEST FOR ACCURACY

**Apparatus.** Centigrade thermometer, graduated from 10° below 0° to 110° above 0°; small glass tumbler; crushed ice or snow; boiler; Bunsen burner; U-tube manometer; pinchcock.

#### INTRODUCTION

In general, solids, liquids, and gases expand when heated and contract when cooled. Most devices for measuring temperature are based on this principle. Those in daily use are the mercury thermometer, the spirit (or alcohol) thermometer, and the metallic (or dial) thermometer. All thermometers are graduated in degrees, but unfortunately there are two scales in use — the centigrade and the Fahrenheit. Each takes as fixed points of reference the melting point of ice and the boiling point of water under standard conditions, but these points are marked differently on the two scales. On the centigrade scale the first point is called 0° and the second 100°, while on the Fahrenheit scale the first point is marked 32° and the second 212°.



To change from one scale to the other, make use of the following formulas:

$$C = \tfrac{5}{9}(F + 40) - 40; \qquad F = \tfrac{9}{5}(C + 40) - 40.$$

#### EXERCISE

*Object.* To test a given centigrade thermometer for accuracy at the 0° point and at the 100° point.

*Method.* 1. Fill the tumbler two-thirds full of crushed ice or snow. Pour in just enough water to float the ice, and then insert the thermometer, burying the bulb in ice up to the 0° point. After waiting about five minutes, to give the mercury time to descend as far as it will, read the thermometer to one tenth of a degree, and record as the freezing point of your thermometer. The difference between this reading and 0° C. is the error.

2. Fill the boiler half full of water. Thrust the thermometer carefully through the stopper into the upper part of the boiler, leaving the 100° point in sight just above the stopper (see illustration). Close the outlet tube *e* with a bit of rubber tubing and a pinchcock. Make sure that the outlet tube *o* is wide open throughout its entire length (the U-tube manometer is to be added later), then light the burner and boil the water. Let the steam flow around the thermometer for several minutes or until the mercury has risen as far as it will, and then read the thermometer to a tenth of a degree. Record this reading as the boiling point of your thermometer. Read the barometer in centimeters, and record.

The true boiling point of water or the temperature of freely escaping steam varies with the barometric pressure. It is to be taken as 100° C. only when the barometer stands at 76 cm. An increase or decrease of 1 cm. in the barometric pressure increases or decreases the boiling point by .37° C. Thus, if the barometer reads 77.2, the boiling point of water is $100 + (77.2 - 76) \times .37° = 100.44°$ C.; similarly, if the barometer stands at 74, the boiling point of water is $100 - (76 - 74) \times .37° = 99.26°$C. Compute the true boiling point and the error of your thermometer, and record.

3. (Optional.) By means of a short piece of rubber tubing, attach the U-tube manometer, partly filled with mercury, to the outlet tube *o*. Open the pinchcock below. Adjust the burner until, with the mercury at the same level in the two arms of the manometer, there is a steady flow of steam through the outlet tube *e*. Gradually reduce the flow of steam through *e* by means of the pinchcock. Note the effect on the gauge and on the thermometer. By careful measurements upon the manometer

determine the increase in the temperature of steam corresponding to an increase of 1 cm. in the barometric pressure and the increase in pressure corresponding to an increase of 1° C. in the temperature of steam. Compare with the facts stated in paragraph 2 above.

### PROBLEMS

**1.** What is the effect of a large bulb and a small bore upon the length of the degrees on a given thermometer?

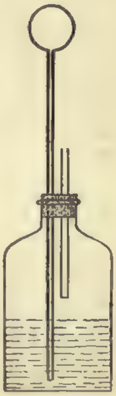
**2.** Change the following thermometer readings to centigrade: 0° F., 32° F., 212° F., 68° F., – 40° F., – 479° F. Change these to Fahrenheit: 0° C., – 40° C., 100° C., – 273° C.

**3.** Find the boiling point of water in each case under the following conditions of barometric pressure: 77 cm. of mercury; 31 in. of mercury; 35 ft. of water; 13.2 lb. per square inch; in a vacuum.

### TOPICS FOR FURTHER STUDY AND INVESTIGATION

The air thermometer of Galileo: experiments.

*Suggestions.* The air-thermometer tube (see illustration) should be about 15 in. long, with an internal diameter of 2 mm., and its open end should reach below the water in the bottle. The water column may be adjusted as follows: Warm the bulb by holding it in one hand until two or three bubbles of air are seen to escape from the open end of the tube. Remove the hand. As the bulb cools, the water rises in the tube. It should reach to a point about halfway up the tube. If it does not rise high enough, warm the hands by rubbing them together, and try again. The instrument may be graduated, if desired, by comparison with a mercury thermometer placed beside it, and the attachment of a paper scale.



Breathe upon the bulb. Blow air upon it. Wet the bulb by the use of a sponge and again blow upon it. Wet the bulb with alcohol or ether and once more blow upon it. Explain.

Make use of your air thermometer to compare the temperature of the air in the laboratory a few feet above your head with that near the floor. Which is the warmer? Explain.

Test the air near the windows and that near the center of the room.

Which is the more sensitive, the mercury thermometer or the air thermometer? Why is not the air thermometer more commonly used?

Design an air thermometer in which the degrees shall be much longer than in your own apparatus. Design one in which they shall be much shorter.

Bring a thermometer from your home for comparison with the best thermometer in the laboratory.

Determine the temperature in your living room at 8 P.M. on several successive evenings, and report. Ask your family physician what temperature he advises for your study at home and for the family living room.

What temperature is the janitor expected to maintain in the school building?

Maximum and minimum thermometers.

Recording thermometers.

The clinical thermometer and its uses in the home.

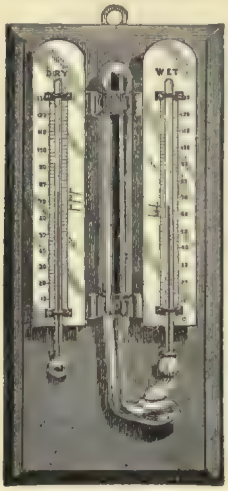
Cooking-range thermometers.

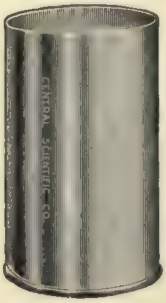
Bath thermometers. (The proper temperature for a hot bath is about 110° F.; for a warm bath, 96° F.; for a tepid bath, 85° F.; for a temperate bath, 78° F.; for a cool bath, 65° F.; and for a cold bath, 50° F.)

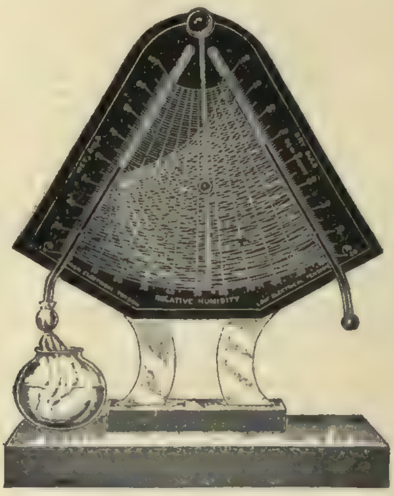
## 17. STUDY OF THE AIR

### DEW POINT: RELATIVE HUMIDITY

**Apparatus.** Centigrade thermometer; a highly polished calorimeter, or metal cup; quantity of ice or snow; salt; wet- and dry-bulb hygrometer or a hygrodeik.







#### INTRODUCTION

*Relative humidity* is a term used to express the percentage of water vapor actually present in the air at a given temperature as compared with the amount which it is possible for it to contain at that temperature. The *dew point* is the temperature at which the water vapor in the air begins to condense in the form of mist or dew.

During a muggy day in summer, with the humidity at 90 per cent and the temperature at 75° F., we complain of the heat, while in midwinter, with the indoor humidity at 25 per cent (the parched air in our living rooms being often drier than the desert of Sahara) and the temperature at 70° F., we complain of the cold, and sometimes feel chilly, when not exercising, at a temperature of even 75° F. In the one case, by reason of the great amount of moisture already in the air, the insensible perspiration cannot evaporate freely, and the internal heat accumulates; in the other case the bodily moisture evaporates so freely in the warm, dry air that the heat escapes unduly and the body becomes chilled.

This excessive dryness of our rooms in winter is said by good authorities to be the cause of many of our national ailments. The delicate membranes of the nose and throat become irritated by the increased evaporation, and one suffers from colds, sore throats, and the like. Our household furniture shows the drying effect of this indoor air during the winter months, by its continual shrinking and opening at the joints; potted plants also, by the amount of water required to keep them alive and by the dryness of their leaves. This condition of things may be corrected in any case by increasing the moisture in the air through the evaporation of water from open dishes until the humidity becomes normal and the room may thus be made hygienic and comfortable at a temperature of even 65° F.

Since moist air acts thus as a blanket to keep us warm, and at the same time is more easily heated than dry air, it follows that a considerable saving in the cost of fuel is also possible if the humidity is kept at the proper point.

A temperature of from 65° to 68° F., with a relative humidity of from 50 to 60 per cent for our living rooms, is regarded as good practice in this country (U S A)

(England)

## EXERCISE

*Object.* To determine the dew point and the relative humidity of the air in the laboratory at the time of the experiment.

*Method.* Three methods are here given; use any of these, as most convenient.

1. *Calorimeter.* Place the thermometer in the calorimeter. Pour in enough water at the temperature of the room to cover the bulb of the thermometer. Add small quantities of cracked ice or snow, and finally of salt, if necessary, stirring the mixture continually and keeping close watch of the outside of the cup, until a mist forms upon the bright surface next to the bottom of the calorimeter. Note the temperature at once. Warm the calorimeter gradually by the addition of lukewarm water in small quantities, keeping the contents well stirred all the while and watching the outside carefully, until the mist disappears. Note the temperature. The average of these two temperatures should give a close approximation to the dew point. Care must be taken not to breathe upon the calorimeter during the experiment. Why? Repeat the experiment and record the average of the several results, if not more than two degrees apart, as the actual dew point.

Determine the relative humidity as follows: Record the temperature of the room in degrees centigrade. Under $t$ in the table below find the observed dew point and the observed temperature of the air. The figures opposite these, under $w$, will give, respectively, the quantity of water vapor (in grams per cubic meter) actually present in the laboratory, and the quantity possible at the existing temperature. Divide the first quantity by the second. Record in the form of a percentage.

Weight of Water in Grams Contained in One Cubic Meter of Saturated Air at Various Temperatures

| $t$ | $w$ | $t$ | $w$ | $t$ | $w$ | $t$ | $w$ |
|---|---|---|---|---|---|---|---|
| – 10° | 2.1 g. | 0° | 4.9 g. | 10° | 9.4 g. | 20° | 17.2 g. |
| – 9 | 2.4 | 1 | 5.2 | 11 | 10.0 | 21 | 18.2 |
| – 8 | 2.7 | 2 | 5.6 | 12 | 10.6 | 22 | 19.3 |
| – 7 | 3.0 | 3 | 6.0 | 13 | 11.3 | 23 | 20.4 |
| – 6 | 3.2 | 4 | 6.4 | 14 | 12.0 | 24 | 21.5 |
| – 5 | 3.5 | 5 | 6.8 | 15 | 12.8 | 25 | 22.9 |
| – 4 | 3.8 | 6 | 7.3 | 16 | 13.6 | 26 | 24.2 |
| – 3 | 4.1 | 7 | 7.7 | 17 | 14.5 | 27 | 25.6 |
| – 2 | 4.4 | 8 | 8.1 | 18 | 15.1 | 28 | 27.0 |
| – 1 | 4.6 | 9 | 8.8 | 19 | 16.2 | 29 | 28.6 |
| 0 | 4.9 | 10 | 9.4 | 20 | 17.2 | 30 | 30.1 |

Compute the total amount of water vapor in grams actually present in the air of the laboratory and the amount that must be added by evaporation to completely saturate the air at the temperature of the room. The dimensions of the laboratory, in meters, may be obtained from the instructor.

2. *Wet- and dry-bulb hygrometer.* The evaporation of moisture from the wick surrounding the bulb of the wet thermometer cools that bulb and causes a difference in reading of the two thermometers known as the depression of the wet bulb.

Since this difference is dependent upon the dryness of the air, it is at once seen to be possible, by the use of such an instrument, to determine the relative humidity of the air.

See that the dish is full of water and that the wick, as well as the muslin surrounding the thermometer bulb, is thoroughly saturated. Fan the wet bulb for a few minutes in order to secure a proper circulation of air. Then, by consulting the table on the following page, determine the relative humidity and the number of grams of water vapor in the air of the entire laboratory at the time of the experiment.

The dimensions of the laboratory may be obtained from the instructor.

### RELATIVE HUMIDITY

Per Cent: Fahrenheit Temperatures

| Air temp. $t$ Dry bulb | Depression of wet-bulb thermometer ($t - t'$) | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5.0° | 6.0 | 7.0 | 8.0 | 9.0 | 10.0 | 11.0 | 12.0 | 13.0 | 14.0 | 15.0 | 16.0 | 17.0 | 18.0 | 19.0 | 20.0 | $g$ |
| 63° | 74 | 69 | 64 | 60 | 55 | 50 | 46 | 42 | 37 | 33 | 29 | 25 | 21 | 17 | 13 | 10 | .41 |
| 64 | 74 | 70 | 65 | 60 | 56 | 51 | 47 | 43 | 38 | 34 | 30 | 26 | 22 | 18 | 15 | 11 | .43 |
| 65 | 75 | 70 | 66 | 61 | 56 | 52 | 48 | 44 | 39 | 35 | 31 | 27 | 24 | 20 | 16 | 12 | .44 |
| 66 | 75 | 71 | 66 | 61 | 57 | 53 | 48 | 44 | 40 | 36 | 32 | 29 | 25 | 21 | 17 | 14 | .46 |
| 67 | 75 | 71 | 66 | 62 | 58 | 53 | 49 | 45 | 41 | 37 | 33 | 30 | 26 | 22 | 19 | 15 | .47 |
| 68 | 76 | 71 | 67 | 62 | 58 | 54 | 50 | 46 | 42 | 38 | 34 | 31 | 27 | 23 | 20 | 16 | .49 |
| 69 | 76 | 72 | 67 | 63 | 59 | 55 | 51 | 47 | 43 | 39 | 35 | 32 | 28 | 24 | 21 | 18 | .50 |
| 70 | 77 | 72 | 68 | 64 | 59 | 55 | 51 | 48 | 44 | 40 | 36 | 33 | 29 | 25 | 22 | 19 | .52 |
| 71 | 77 | 72 | 68 | 64 | 60 | 56 | 52 | 48 | 45 | 41 | 37 | 33 | 30 | 27 | 23 | 20 | .53 |
| 72 | 77 | 73 | 69 | 65 | 61 | 57 | 53 | 49 | 45 | 42 | 38 | 34 | 31 | 28 | 24 | 21 | .55 |
| 73 | 78 | 73 | 69 | 65 | 61 | 57 | 53 | 50 | 46 | 42 | 39 | 35 | 32 | 29 | 25 | 22 | .57 |

Opposite the reading of the dry bulb, under the number representing the difference between the wet and the dry bulb, is to be found the relative humidity.

In the column headed $g$ is given the number of grams of water vapor per cubic foot required to completely saturate the air at the corresponding temperatures. To determine the amount of water vapor actually present, multiply by the relative humidity expressed as a percentage.

3. *Hygrodeik.* (Directions for use are taken from the manufacturer's catalogue.) Swing the index arm over to the left; loosen the screw that holds the slider in place upon the index hand, and slip the latter up or down until the pin attached stands exactly opposite the reading of the wet-bulb thermometer; then swing the index arm to the right until the pin strikes the curved line (usually printed in red) running down from the reading of the dry-bulb thermometer. The lower end of the index arm will then point to the relative humidity as shown upon the scale at the lower edge of the chart. While the index hand is still in place for pointing out the relative humidity, follow the curved line (usually printed in black) leading down to the right from the point of the slider, till it strikes the dry-bulb thermometer; the reading thus indicated is the dew point. Finally, trace the same curved line backward to its other extremity, and you will find a number indicating grains (per cubic foot) of water vapor in the air of the room at the time of the experiment. See that the dish at the left is nearly full of water and that the wick and muslin cloth surrounding the bulb of the thermometer are thoroughly wet.

Find the dew point, the relative humidity, the number of grams of water vapor in one cubic foot of air space, and the number of grams of water vapor in the entire laboratory. The dimensions of the laboratory may be obtained from the instructor. To change grains to grams, multiply by .065.

#### PROBLEM

Good health requires that the relative humidity be in the neighborhood of 60 per cent. How many grams of water vapor must be added to the air of our laboratory to-day to bring the relative humidity up to the standard?

### TOPICS FOR FURTHER STUDY AND INVESTIGATION

Commercial devices for increasing the relative humidity of the air in our homes and offices.

The dew point and the weather.

The sweat glands of the skin as an automatic device for regulating the temperature of the body.

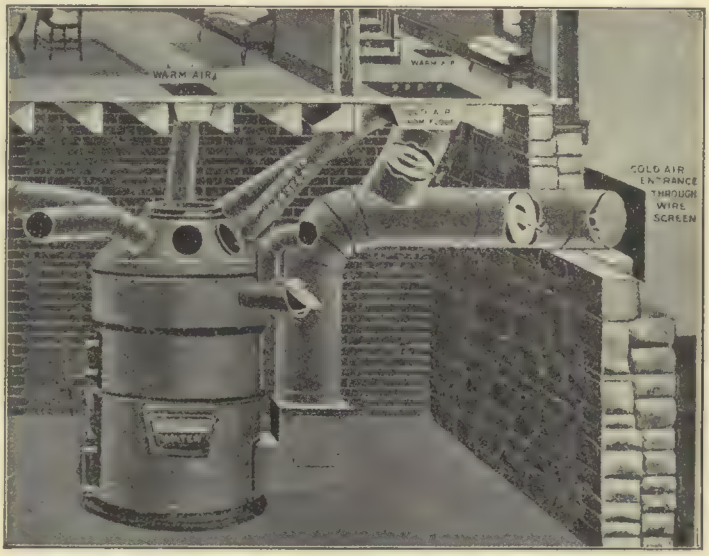
## 18. STUDY OF A DIAGRAM

### THE HOT-AIR FURNACE

**Apparatus.** The diagram on page 35, showing a hot-air furnace with its pipes and connections in place, as arranged for the heating of a small house.

A hot-air furnace in actual operation. This can probably be found, if not in your own home, in some dwelling house near at hand, or possibly in the school building itself.

Various commercial catalogues. These may usually be obtained from local dealers for the asking or may be ordered by mail from addresses given in the advertising columns of the monthly magazines.



#### INTRODUCTION

The fundamental principles underlying the operation of the hot-air furnace, so commonly used in this country, are of the simplest order.

The furnace consists of a large stove, usually of cast iron, completely inclosed (save for the doors in front and the smoke pipe) by a casing, or jacket, of brick or galvanized iron. The outdoor air, entering this jacket at the bottom through a large pipe known as the cold-air box (see diagram), becomes heated by contact with the hot stove, expands, grows lighter, is pushed upward by the colder air below through the large pipes extending from the upper end of the jacket, and finally enters the rooms through registers in the side walls or in the floors.

The movement may be made continuous by allowing the air to flow back to the cold-air box through a return pipe, to be heated over again after it has become chilled, or by providing some way of escape for the cooler air — through an open fireplace or through a register opening into the chimney flue near the floor. Which is the better plan? Why? If there is no possible escape provided, the influx of hot air soon ceases. Our houses are generally so open, however, about the doors and windows that little difficulty is experienced on this score.

Once within the room the warm air gradually rises to the ceiling, distributes its heat by diffusion, moves over to the colder side of the room, falls down by the windows to a point near the floor, and is slowly driven out by the steady pressure of the incoming supplies of fresh air from the furnace.

It will be seen that such a heating system meets all the conditions for an ideal system of ventilation, provided always that suitable exits are arranged for the escape of the foul air, and that proper care is taken to insure a continuous supply of pure air to the cold-air box. If one does not care to breathe the air from the cellar or the dust from a rubbish heap out of doors, he must take care that the air which enters his house through the register does not come from either of these places.

The area of the opening of the cold-air box should be equal to the sum of the areas of all the registers, less about one sixth to allow for expansion. Good practice allows 2 sq. ft. of area in the register opening for each 10,000 cu. ft. of air space in the room to be heated.

All concealed pipes should be double, one inside of the other, with air spaces between, to insure safety from fire. Cellar pipes may be covered with asbestos to prevent loss of heat.

## EXERCISE

This exercise and similar ones that follow may be taken up at first as a joint exercise in class or may be assigned as home work.

*Object.* To give practice in the interpretation of a diagram and to teach the main facts concerning the operation of a hot-air furnace.

*Method.* Examine the diagram in detail.

1. Write an article upon The Hot-Air Furnace, embodying (in any order you choose) correct answers to as many of the following questions as possible, the necessary information to be gathered from the diagram, from trade catalogues, from reference books to be found in the library, and, above all, from your own experience.

*Questions.* Upon which side of the house should the cold-air box *P* be placed? Why?

What relation should exist between the area of the cross section of the cold-air pipe *P* and the sum of the areas of the pipes marked *J*?

What advantages does a galvanized-iron cold-air box possess over a wooden one?

What is the object of the dampers *K*? Why will not the registers at *L* answer the same purpose?

Why is the hot-air pipe leading to the second story of smaller cross section than that leading to the first story?

What provision is made for the exit of air from the rooms? Suggest several good schemes, stating the advantages of each.

Make a copy of the parts of the diagram needed for your purpose and indicate by means of arrows the probable course of air currents in the room at the right upon the first floor and at the left upon the second floor, on the supposition that there is a fireplace near the center at the back of each room.

What is the object of the damper at *Q*? What will be the effect upon the circulation of air if *Q* is closed and *R* is open? if both *Q* and *R* are closed?

It sometimes happens that one register in the house is cold and the room chilled, while all the others are warm. Explain and suggest a remedy.

It occasionally happens that the delivery of air to some room, remote from the furnace perhaps, is very slow. Mention several possible causes and suggest remedies.

What is the latest opinion concerning the utility of the hot-water pan *G*?

Is there any connection between the circuit of air referred to in the introduction and the one that supplies the draft for the fire? Describe the second circuit beginning at the openings in door *F*.

What is the purpose of the drum *B*?

Distinguish between the direct draft and the indirect draft. Is any such arrangement shown here?

Mention several causes of poor draft and suggest remedies.

Describe in detail the check damper at *N*, with a clear explanation of the principle upon which it is supposed to work.

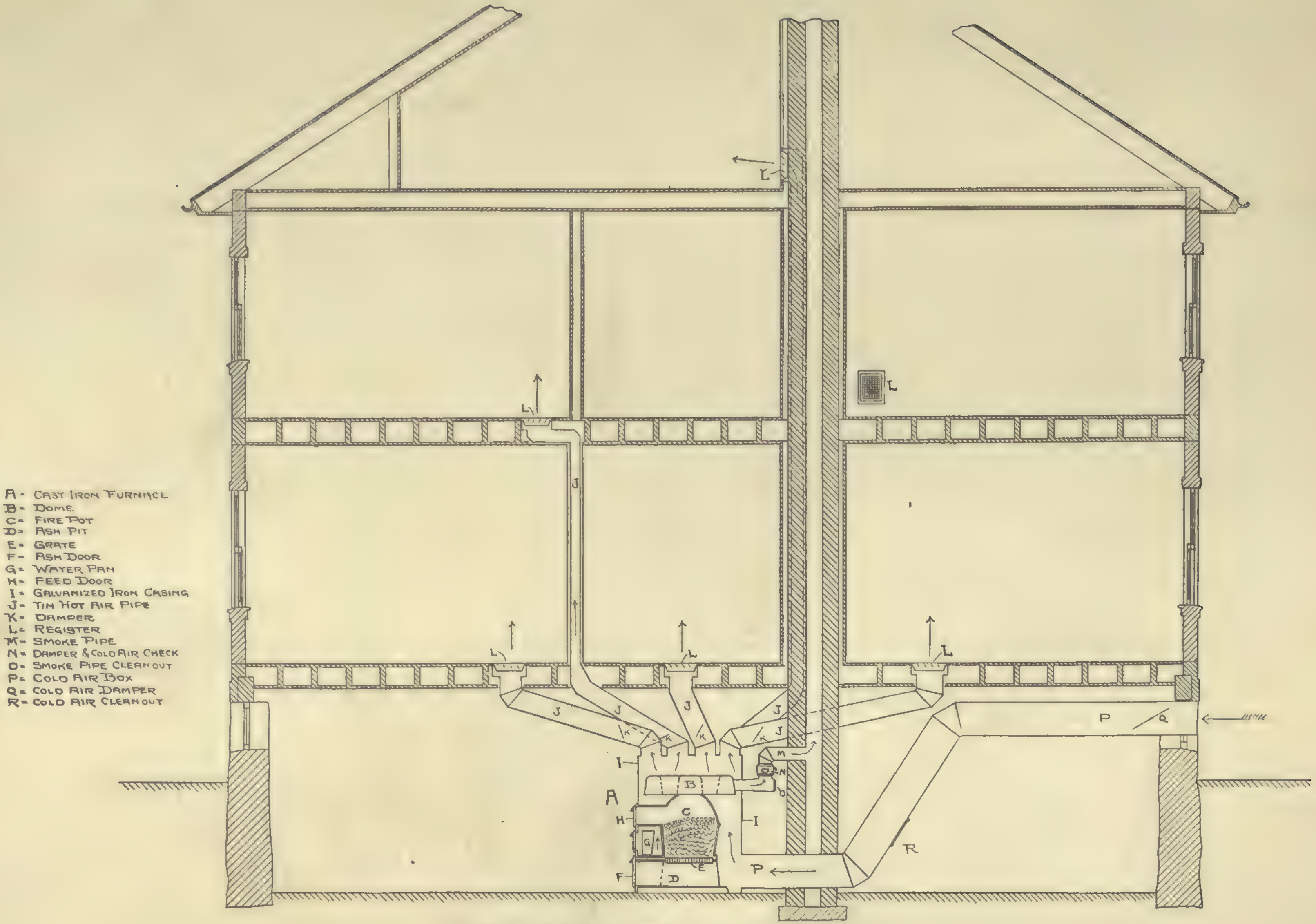
What is the object of the slide in the upper door of the furnace?

How do you account for the fact that smoke sometimes comes up through the hot-air pipes when a new fire is started, and that dust and ashes also rise when the fire is vigorously shaken? How can these annoyances be avoided?

Coal gas occasionally comes up through the hot-air pipes. Is this a serious matter? How can it be avoided?

A grate bar at *E* occasionally breaks down, or "burns out," as the engineer says. Why does this happen? How may it be avoided?

2. Secure a catalogue from the makers of the furnace used in your home or your chum's home, if either house is heated by this method, and write a brief description of the home plant, illustrated by the use of cuts from the catalogue.



Hot-Air-Furnace Heating Apparatus

Sizes of pipe. To determine the size of furnace pipe suitable for any given room, and to lay out a plan for an entire house, a well-known authority makes use of the following rules:

For the first floor: Find the cubic contents of the room in cubic feet, divide this by 25, and the result will be the proper area of pipe for the room. Use the nearest regular size (see table below).

For the second and third floors: Proceed as above, but divide by 35, and use nothing smaller than a 7-inch pipe.

Locate registers at the nearest convenient points to the furnace, giving preference to the inner wall of the room in each case. Locate the furnace so that all pipes may be as nearly equal in length as possible, favoring the cold side of the house if lengths must be unequal.

Make the area of the cold-air box at least three fourths as large as the combined areas of the hot-air pipes.

Select a furnace that is guaranteed to care for the computed pipe area, and but little trouble will be experienced in heating the house.

AREA OF HOT-AIR PIPES

| SIZE Inches | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 14 | 16 | 18 | 20 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AREA Square inches | 28 | 38 | 50 | 64 | 78 | 95 | 113 | 154 | 201 | 254 | 314 | 452 |

Test your home plant if the house is heated by a furnace, and determine whether or not it conforms to the above rules.

Claims made by various manufacturers for particular types of hot-air furnaces.

Kinds of coal suitable for furnace use, with relative heating values and cost per ton delivered at your home.

Advantages and disadvantages of heating by hot air.

Scientific rules for the care of a furnace; make up a set of your own.

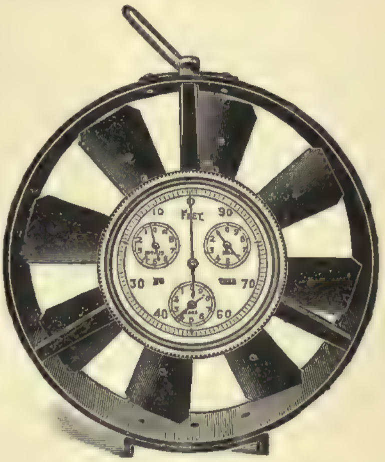
Fuel economy.

Stoves. By weighing coal and ashes determine the percentage of ash; 16 per cent is a fair average.

## 19. STUDY OF AIR CURRENTS

### USE OF AN ANEMOMETER: VENTILATION

**Apparatus.** A *Biram's Anemometer* (see illustration), four inches in diameter, having a disconnector attached and having a dial upon which are four circles registering to one hundred thousand feet and then repeating. This instrument is for registering the velocity of currents of air in flues and ventilating chambers, as well as through open doors, windows, and other air passages.



*Instructions for use* (taken from the manufacturer's catalogue). By means of the small key accompanying the instrument, set all the hands at 0. Then, having placed the instrument in the airway to be tested, with the fan wheel *facing the current*, release the disconnector (a small lever projecting from the top of the instrument and used for throwing the registering mechanism in and out of gear) by pushing it to one side, and the observation is commenced. At the end of the period of observation, replace the disconnector and throw the movement out of action; the result may then be read off. Commencing with the highest circle, note carefully what figure the index has *actually passed*, and add to this in turn the figure last passed by the index of each succeeding circle, ending with the largest one. If the instrument used is not fitted with the *zero-setting* attachment, it will be necessary, *before* commencing the test, to note carefully the sum of the previous observation; then, when the test is ended, deduct the amount already noted; the difference represents the number of feet of air passed during the observation, and this, multiplied by the area (in square feet) of the airway, will give the number of cubic feet of air registered. To find the pressure in pounds per square foot, multiply the square of the velocity in feet per second by .0023.

In practice, engineers often ignore the zero-setting device and the readings of the smaller circles, keeping actual count, instead, of the number of revolutions per minute made by the big hand alone and multiplying the result by 100 for the velocity in feet.

A table showing the correction to be applied for various velocities usually accompanies the instrument. An average velocity of about 300 ft. per minute is to be expected in the study of schoolroom ventilation.

#### INTRODUCTION

An abundance of pure air is essential to health. In certain states the law requires that each pupil in the public schools be supplied with 30 cu. ft. of fresh air per minute and 250 cu. ft. of air space in which to breathe. By the Natural System of ventilation the necessary change of air is effected by the use of doors and windows, often with the assistance of fireplaces, small flues, and the like. Such a system is adapted only to small buildings containing very few people. Buildings occupied by large numbers of people must be supplied with some artificial means of moving the air, so that the large quantities of fresh air required may be brought in at the desired rate and the foul air taken out. If this change of air is accomplished by the rise and fall of the air itself (due to the changes in density caused by expansion under heat), through a series of flues or large pipes provided for the purpose, the method is known as the Gravity System. If, on the other hand, the air is forced through such flues by means of some sort of fan driven by power, the method is designated as the Fan System — *plenum* when the pure air is driven into the room by the fan while the foul air escapes through open ducts or flues, *exhaust* when the foul air is sucked out of the room by the fan and the pure air rushes in through open ducts or in some cases through the openings about the doors and windows. Which method is employed in our own building? in your church?

## EXERCISE

*Preliminary.* Open one of the windows about a foot, if the day is not too cold. Compute the area of the opening in square feet. By means of a stout cord suspend the anemometer in the center of the opening (remembering all the time that you are handling a delicate and valuable instrument), the dial facing you, taking pains not to obstruct the passage of air by standing too near, and determine the number of cubic feet of air passing through the open window in one minute — *in* if the large index hand moves forward in the same direction as the hands of a watch, *out* if it moves backward.

*Object.* To determine whether the ventilation system as applied to the physical laboratory, or other room designated by the teacher, is accomplishing what it should.

*Method.* See that all the doors and windows are closed.

Hold the anemometer in front of the register (about three inches from its face) through which the pure air enters the room, and determine the average velocity of inflow in feet per minute by finding the actual velocity at a number of points, distributed as widely as possible over the face of the register, and dividing by the number of trials. Then, by multiplying the average velocity by the number of square feet in the area of the opening just behind the register (deducting 30 per cent from the result if the face of the register is in the form of any of the common cast-iron patterns, or 10 per cent if it is of wire netting), compute the number of cubic feet per minute of fresh air entering the room through this duct.

Determine the amount of air taken out of the room through the foul-air duct by the same method.

Compare the results. Account for any discrepancy.

How many cubic feet of fresh air per hour is supplied to the laboratory by the ventilating system provided? How many pupils would this provide for in accordance with the regulations of the school board?

If time permits, go down to the engineer's room, ascertain how much fresh air enters the building, and from your own observations determine what per cent of this air gets into the physical laboratory.

At what temperature does the fresh air enter the room? At what temperature does the foul air leave it? What is the relative humidity in each case?

## TOPICS FOR FURTHER STUDY AND INVESTIGATION

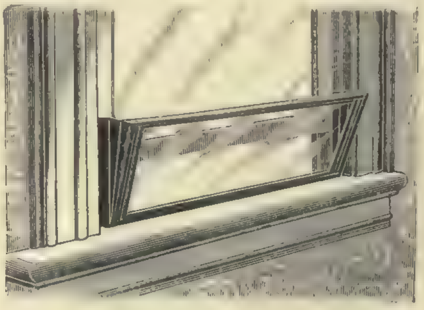
Amount of air actually transferred under widely varying conditions in the process of ventilating a room by the use of an open window.

Movement of air about the laboratory in the neighborhood of doors and windows, to be determined by the behavior of the smoke rising from a lighted joss stick. Illustrate by the use of sketches, using arrows to show direction of air currents.

Ventilation of rooms at home: methods.

Experiment with the joss stick to determine the best arrangement of open windows for a good circulation of air.

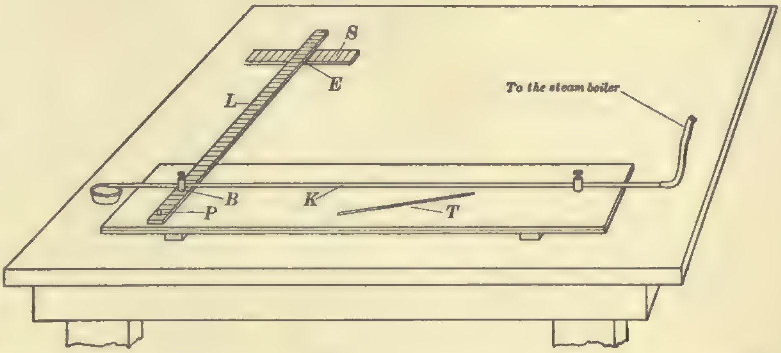
The illustration shows an excellent device for preventing a disagreeable draft. Suggest others.



## 20. STUDY OF A SOLID

### EXPANSION BY HEAT: COEFFICIENT

**Apparatus.** Compound bar of brass and iron (to illustrate the unequal expansion of metals); linear-expansion apparatus (see illustration); boiler; Bunsen burner; rubber tubing; various solids (aluminum, brass, steel, glass) each in the form of a tube $\frac{1}{4}$ in. in external diameter and about 30 in. long; shallow dish to catch the drip from the condensing steam; centigrade thermometer.



#### INTRODUCTION

It is a familiar fact that nearly all solids, especially those of a crystalline nature, expand when heated and contract when cooled, but the exact amount of this change in size for the various materials used in the industrial arts is not so widely known.

Heat the compound bar in the flame of a Bunsen burner until it is nearly red-hot throughout its entire length; then sight along its edge. Explain. Cool the bar by immersion in ice water and test it again in the same way. Explain. Do you know of any commercial device in which practical use is made of such a compound bar? Which expands the more when heated, iron or brass?

The exact amount by which a given body increases in size when heated depends upon three things: the increase in temperature to which the body is subjected, the size of the body before being heated, and the material of which the body is composed. Increase in volume is known as cubical expansion; increase in length, as linear expansion. *Definition:* The fraction of itself by which a given substance increases in length when heated through one degree is called the coefficient of linear expansion.

The force displayed by a metal bar while attempting to change its length in response to a change in temperature is often prodigious, being equal, in fact, to the force that would have to be applied from without in order to stretch the bar, or to compress it, by a like amount without any change in temperature. Imagine the force needed to compress a bar of steel two inches in diameter by as much as one sixteenth of an inch, and you have some idea of the resistance that must be offered to keep the same bar from expanding under an increase in temperature. This gigantic force of expansion and contraction has been utilized to some extent in the arts and sciences, but more often must be allowed for in some way, since it can seldom be controlled. Telephone wires are therefore stretched loosely in summer, expansive joints are introduced at various points in steel rails and bridges, furnace bars are set loosely upon their bearings, and steam pipes are left unfastened, to allow for changes in temperature.

#### EXERCISE

*Object.* To determine by what fraction of itself a given tube of metal or of glass expands in length when heated through one degree centigrade.

*Method.* Arrange the apparatus as in the illustration, the tube *K* being slipped through the two binding posts and, by means of the thumb screws, secured firmly in place while the lever *L* is kept all the while at right angles to the length of the tube. Adjust the scale *S* by moving it about under the lever *L* until the distance *PE*, as measured on the lever from the center of the pivot *P* to the edge of the scale *S*, is exactly ten times the distance *PB* from the center of the pivot *P* to the center of the binding post *B*.

Measure the distance between the two binding posts from center to center and record as the initial length of the tube (see *Form of Record*). Read the thermometer $T$ near the tube and record as the initial temperature. Note the exact position of the lever with reference to the scale $S$ by looking squarely down on it at $E$. Pour a cupful of water into the boiler; light the Bunsen burner; boil the water and allow the steam to flow freely through the tube. Observe the movement of the lever over the scale $S$ and record its amount as the movement of the pointer; divide by 10 (why?) and record the result as the linear expansion of the tube.

Read the barometer; compute the temperature of steam (see Study of a Mercury Thermometer) and record as the final temperature. Complete the tabular statement.

(*Form of Record*)

### STUDY OF A SOLID

### EXPANSION BY HEAT: COEFFICIENT

*Object:* To determine the coefficient of linear expansion of

*Data*

Initial length of the tube ($l$)........................................ cm.
Initial temperature........................................ °C.
Movement of the pointer........................................ cm.
Final temperature........................................ °C.

*Computations and Conclusion*

Rise in temperature........................................ °C.
Linear expansion of the tube........................................ cm.
Linear expansion per degree ($e$)........................................
Coefficient of linear expansion $\left(\frac{e}{l}\right)$........................................

### PROBLEMS

**1.** Which will break the more readily if filled with water and placed over a Bunsen burner, a thin glass vessel like a beaker or a thick one like a tumbler? Explain.

**2.** How much will a bar of iron that is 6 ft. long expand in length if heated 50° C.? (Coefficient of linear expansion of iron, .000012.)

**3.** What allowance must be made for the "come and go" of an iron pipe that is 30 ft. in length at 0° C. if the pipe is to be subjected to a change of temperature ranging from the freezing point of water to the boiling point?

**4.** How much does the Brooklyn Bridge expand in length from winter to summer, if the bridge is 6600 ft. (1¼ miles) long and undergoes a change in temperature of from − 10° to 110° F.?

### TOPICS FOR FURTHER STUDY AND INVESTIGATION

Thermostats.
Metallic thermometers.
Setting steel tires on locomotive wheels and on carriage wheels.
Jacketing the big guns of the navy.
Expansion joints in steel bridges and elevated railway tracks.
Hot boxes on railway cars.
Frequent peeling of nickel-plated articles.
Disintegration of rocks to form soil.
Compensation in clocks and watches for change in temperature.

## 21. STUDY OF A SOLID

### SPECIFIC HEAT

**Apparatus.** A small cylinder of aluminum, brass, copper, iron, or porcelain, with a hook in one end for suspension, or a rough block of the same material; boiler; Bunsen burner; platform balance; metric weights; thermometer; calorimeter.

### INTRODUCTION

Thermometers measure changes in temperature or intensity of heat, but by themselves tell nothing about the quantity of heat involved in such changes. It is evident, however, that to raise the temperature of ten pounds of water through a given number of degrees must require ten times as much heat as to raise the temperature of one pound of water through the same number of degrees. To measure quantity of heat, therefore, we must know the weight of the material heated, as well as the number of degrees through which it is heated, and on this principle are based the two units, in daily use, for the measurement of quantity of heat.

The *British Thermal Unit* (B.T.U.) is the quantity of heat required to change the temperature of one pound of water one degree Fahrenheit.

The *gram-calorie*, or, briefly, the *calorie*, is the amount of heat required to change the temperature of one gram of water one degree centigrade.

How many B.T.U. are required to heat 5 lb. of water 10° F.? 15 lb. 6° F.?

How many calories are given out by 250 g. of water in cooling from 100° C. to 20° C.?

Different substances vary greatly in their capacity for heat. To raise the temperature of one pound of brass one degree, for instance, requires only about one tenth as much heat as to raise the temperature of one pound of water one degree.

The specific heat of a substance is the number of B.T.U. required to change the temperature of one pound of the substance one degree Fahrenheit.

The specific heat of a substance is the number of calories required to change the temperature of one gram of the substance one degree centigrade.

How many calories are required to heat 150 g. of brass (specific heat .1) from 20° to 60° C.?

### EXERCISE

*Object.* To determine the specific heat of a given solid.

*Method.* The method employed is based on the following principles: If a hot solid is dropped suddenly into a vessel of cold water, the heat lost by the solid is equal to the heat gained by the water plus the heat gained by the containing vessel. The amount of heat lost or gained by any substance equals specific heat × weight × change in temperature. (The specific heat of water is 1; it is greater than that of any other substance save liquid hydrogen. The specific heat of the material composing the calorimeter used in this exercise is .1.)

1. Weigh the solid in grams and record under *Data* (see *Form of Record*).

2. Weigh the calorimeter. Fill the calorimeter two-thirds full of cold water from the faucet in the laboratory. Find the weight of the water in grams, and record.

3. By means of a thread suspend the solid in the upper part of the boiler, taking care to see that it does not strike the sides of the boiler, and surround it with a flood of steam for at least five minutes; read the barometer; compute the temperature of steam from the observed barometer reading, and record as the initial temperature of the solid.

4. Stir the water in the calorimeter with the thermometer, and record its temperature to a tenth of one degree.

5. Remove the solid from the hot steam and drop it quickly into the water in the calorimeter; stir the water thoroughly with the thermometer, and record its temperature to a tenth of one degree. Complete the tabular statement.

*(Form of Record)*

## STUDY OF A SOLID

### Specific Heat

*Data*

Weight of the solid .................................................... g.
Weight of the calorimeter .................................................... g.
Weight of the cold water .................................................... g.
Initial temperature of the solid .................................................... ° C.
Initial temperature of the water .................................................... ° C.
Final temperature of the water and the solid .................................................... ° C.

*Computations*

Rise in temperature of the water and the calorimeter .................................................... ° C.
Calories absorbed by the water ($a$) ....................................................
Calories absorbed by the calorimeter ($b$) ....................................................
Drop in temperature of the solid ($c$) ....................................................
Calories given out by the solid in cooling 1° C. $\left(\frac{a+b}{c}\right)$ ....................................................
Calories given out by 1 g. of the solid in cooling 1° C. ....................................................

*Conclusion*

The specific heat of .................................................... is ....................................................

## PROBLEMS

**1.** How many calories are given out by 10 g. of mercury in cooling from 100° to 20° C.? See Appendix for Table of Specific Heats.

**2.** What effect has the low specific heat of mercury upon the sensitiveness of a mercury thermometer?

**3.** How many B.T.U. are given out by the water in a hot-water bag (capacity 2 qt.) in cooling from 200° F. to the temperature of the human body (98.3° F.)?

**4.** How many B.T.U. are required to raise the temperature of 5 cu. ft. of water (for a hot-water bath) from 42° to 102° F.?

**5.** How many B.T.U. are absorbed by an aluminum teakettle in changing its temperature from 62° to 212° F.?

**6.** How many B.T.U. are given out by 200 lb. of ice in cooling from 28° to − 10° F.?

**7.** How many B.T.U. are absorbed by a 2-pound flatiron in the process of changing its temperature from 68° to 350° F.?

**8.** Why is the cast-iron dome of a hot-air furnace made so heavy?

**9.** The heat value of a certain kind of coal is 14,000 B.T.U. per pound. How many pounds of this coal must be burned beneath a boiler of 75 per cent efficiency to heat 5 gal. of water from 32° to 212° F.?

## TOPICS FOR FURTHER STUDY AND INVESTIGATION

Effect of the high specific heat of water upon climate: compare coast cities with inland cities. The gulf stream and its effect on the climate of England.

Relative advantages of flatirons, soapstones, and hot-water bags as foot warmers.

Comparison of the porcelain stoves of Germany and the cast-iron stoves of America as conservers of heat.

Measurement of high temperatures. The following experiment may be used to determine the temperature of a Bunsen flame when in practical use and heating a comparatively large body.

*Method.* Use a small iron ball (diameter, $\frac{5}{8}$ in.) as the body to be heated, and a calorimeter of about 300 cc. capacity.

1. Find the weight of the ball in grams; then suspend the ball by means of a thin iron wire in the hottest part of the Bunsen flame (just above the inner cone) and allow it to remain there for at least ten minutes, or until it has become as hot as the flame.

2. Weigh the calorimeter, fill the dish about half full of water from the faucet in the laboratory, and weigh again.

3. Stir the water in the calorimeter with the thermometer, and just before the next event determine its temperature to a tenth of one degree. Push aside the Bunsen flame and instantly surround the white-hot ball with the water in the calorimeter. Stir the water for about a minute, or until the mercury has reached its highest point, and record its temperature with the same care as before.

4. Record the specific heat of iron as .11.

5. Compute the number of calories given out by the ball (received by the water and the calorimeter); then, from the fact that a gram of iron, in cooling through 1° C., gives out .11 calories, compute the drop in temperature of the ball and from this compute its original temperature or the temperature of the Bunsen flame. State the final result in both centigrade and Fahrenheit degrees.

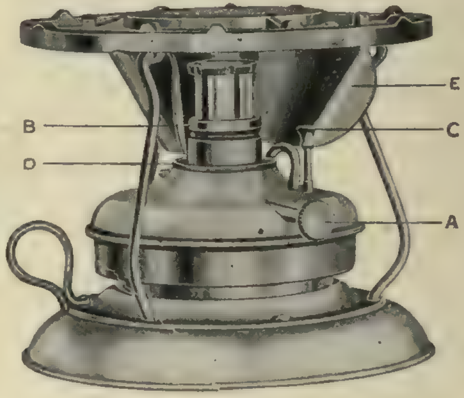
Explain how the temperature of the coal fire in a range could be obtained by the use of a 1-pound iron weight, a small wooden bucket containing a quart of water, and a Fahrenheit thermometer. Try it.

## 22. STUDY OF AN ALCOHOL STOVE

### UTILITY; ECONOMY

**Apparatus.** Alcohol stove; quantity of denatured alcohol; quart measure; platform balance; metric weights; 1-qt. teakettle; Fahrenheit thermometer.

The stove shown in the illustration is known as the "Universal" and is designed to supply a quick, hot fire for all forms of light table cooking.



*Directions for use* (taken from the manufacturer's catalogue). Fill the stove nearly full with the best quality of denatured alcohol. Remove the cap that covers the corrugated tube; then, after turning down (with the thumbscrew *A*) the collar *B*, surrounding the corrugated tube, take two or three strokes with the little pump *C* and apply a lighted match to the alcohol pumped up at *D*. The stove is thus lighted and continues automatically to generate the gas which it burns. By turning the thumbscrew the flame may be regulated from a fierce blow-flame to a low, simmering flame. To extinguish the flame, turn up the collar *B* to the top of the tube and replace the cap. Be sure that the cap is kept on the lamp when the stove is not in use, to prevent evaporation. The wind shield *E* fitted under the heater plate is readily removed and is intended for use chiefly when the stove is used out of doors or in a current of air. Place an asbestos mat beneath the stove for the sake of tidiness.

### INTRODUCTION

The alcohol gas burned in this stove is self-generated in the burner with no loss of heat. The corrugated upright tube incloses the wick; when the stove is filled with denatured alcohol, this wick becomes saturated. When the tube is surrounded by flame, the alcohol in the wick is quickly converted into gas, which comes up through the small holes surrounding the burner and, igniting, creates the blue, intensely hot blow-flame.

In handling the alcohol care must be taken that no flame is brought near it at any time (except for the purpose of lighting the stove), since the fluid is so very inflammable.

### EXERCISE

*Object.* To test the merits and determine the operating cost of a given denatured-alcohol stove.

*Method.* Find the weight in grams of one pint of the denatured alcohol used, or find the specific gravity of the alcohol and compute the weight of one pint from the fact that one pint of water weighs one pound (454 g.).

Weigh the fount empty and again when properly filled ready for use. (The weight of the empty fount may be determined once for all, of course, and the amount marked upon the top, if preferred.) Compute the capacity of the fount in grams and in pints.

Into the kettle pour a quart of water at the temperature of the room and place the kettle upon the stove. Take the temperature of the water. Light the burner. Note the time. Bring the water to the boiling point. Compute the time required.

Extinguish the flame. Weigh the fount and its contents once more. Compute the amount of fuel consumed and its cost at the market price per pint.

From the capacity of the fount and the rate of fuel-consumption in grams per minute, determine how long the stove should be expected to burn at one filling, and the cost per hour.

Compare your results with those obtained by the other members of the class. Account for variations.

Comment upon this apparatus as to appearance, convenience, and fuel economy.

Write up the exercise in good form, and report.

The blue-flame kerosene stove may be studied in the same manner and a direct comparison made between the two appliances if desired.

## TOPICS FOR FURTHER STUDY AND INVESTIGATION

Increase in efficiency of heating apparatus by the use of utensils properly proportioned to the size of the stove.

Composition of denatured alcohol. (Completely denatured alcohol is made up as follows: To 100 gal. of alcohol is added 10 gal. of wood alcohol and ½ gal. of benzine. The purpose of the adulteration is to reduce the cost of the fuel to the consumer, by rendering the fluid unfit for use as a beverage and thus exempting it from the internal revenue tax levied upon spirituous liquors.)

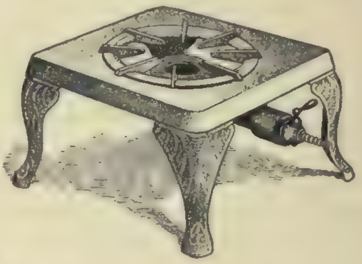
Denatured alcohol in the home: for flatirons, chafing dishes, percolators, and lamps with incandescent mantles (see commercial catalogues).

Solidified alcohol. Determine the efficiency of a stove and kettle making use of "solid alcohol," and report.

## 23. STUDY OF A GAS STOVE

### OPERATING COST; EFFICIENCY

**Apparatus.** Small gas stove, or a "hot plate"; Bunsen burner (to illustrate the fundamental principle of the gas stove); portable gas meter (a 3-light meter of the usual commercial form with a hose connection on either side, or a test meter reading to hundredths of a cubic foot); 2-qt. teakettle; spring balance; Fahrenheit thermometer.



### INTRODUCTION

The gas stove is based upon the principle of the Bunsen burner (invented by Robert Wilhelm Bunsen, a German chemist, in 1857).

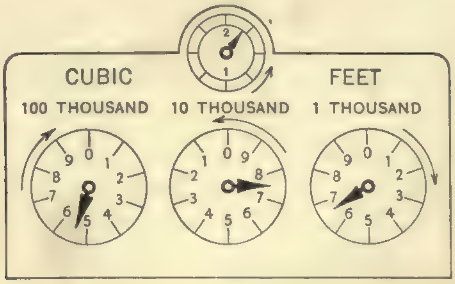
*The Bunsen burner.* Examine the burner in detail; note especially the openings near the base for the admission of air, and the brass collar for the regulation of the air supply. Attach the burner to the gas supply by means of a rubber hose; see that the air supply is wide open; turn on the gas and *then* bring a lighted match to the top of the burner. If the gas burns with a clear blue flame, the burner is acting properly. If the flame is colored yellow and shows a tendency to smoke, the gas is probably on fire *inside* the burner, as can be seen by looking through the air-supply openings; in that case the flame is said to have "struck back" and the burner is improperly lighted; turn off the gas and try again.

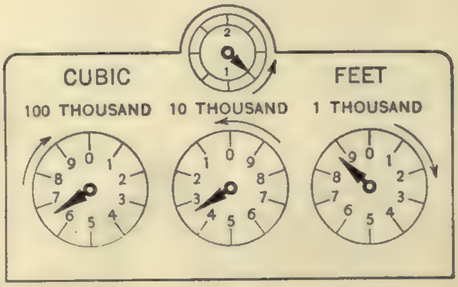
Note the effect of partly closing the air-supply openings; regulate these until the gas burns with a steady blue flame, intensely hot. Hold a small iron wire in the Bunsen flame just above the apex of the inner cone until the iron melts; the temperature at this point is about 1560° C.

*The gas meter.* The dial of a 3-light commercial meter (the ordinary household article, capacity 80 cu. ft. per hour) is shown in duplicate in the illustration below. In measuring such small quantities of gas as are called for in a laboratory exercise of this order, observe only the movement of the index hand in the small circle at the top of the dial. Note the exact position of the index hand when the gas is turned on, the direction of movement, the number of complete revolutions made during the run, and the exact position of the index hand when the gas is turned off; the number of cubic feet of gas consumed can then be easily computed from the fact that one revolution of this particular hand represents 2 cu. ft.

If greater accuracy is required, proceed as follows: Note the time ($t$) consumed in the test and the time ($T$) required by the index hand to make one complete revolution under the same conditions; the amount of gas consumed during the test will then be $\frac{t}{T} \times 2$ cu. ft.

In commercial practice the large circles only are read, and therefore the result is expressed in round numbers, nothing less than 100 cu. ft. being recorded.





The figure at the left represents the dial of a gas meter at the beginning of a month; the one at the right, the same dial after gas has been used a month. Record the two readings (the first is 57,600); compute the amount of gas consumed during the month, and its cost at the market price per 1000 cu. ft.

The dial of a *test meter* is like the dial of an anemometer.

### EXERCISE

*Object.* To test the merits of a small gas stove, or a hot plate, for light table cooking.

*Method.* Examine the stove in detail. Is there any provision for the regulation of the air supply, for the dissection of the burner to clean it, or for the protection of the table from the radiant heat? Are such devices desirable? Should they be found upon the larger sizes?

Connect the gas supply with the meter and the stove in such a manner that the gas may flow through the meter from left to right as you face the dial.

Find the weight of the teakettle in pounds. Pour 2 qt. of water (4 lb.) into the teakettle. Note the temperature of the water. Place the kettle upon the stove; read the meter; note the time and light the gas, taking care that the flame does not strike back. Determine the time required to bring the water to the boiling point, and the quantity of gas consumed. Compute the cost of the gas consumed, the cost per hour, and the cost per quart of water heated. Compute the rise in temperature of the water and the kettle, the number of B.T.U. (see Study of a Solid: Specific Heat) absorbed by the water, the number of B.T.U. absorbed by the kettle, and the number of B.T.U. supplied by the gas. If no other data are available, assume that the specific heat of the kettle is .1 and that 1 cu. ft. of gas, in burning, gives out 600 B.T.U. Compute the efficiency of the combined apparatus (the stove and the kettle) by finding the ratio between the heat received by the water and the heat supplied by the gas; that is,

$$\frac{\text{Useful heat (B.T.U.)}}{\text{Total heat (B.T.U.)}} = \text{per cent efficiency.}$$

Comment upon the apparatus as to appearance, convenience, and fuel economy. How could its efficiency be increased? What precautions are to be observed in its use? Report.

### PROBLEMS

**1.** Does water grow hotter after it begins to boil? In boiling meats and vegetables, is anything gained by boiling the water vigorously? Why does a tin teakettle melt down after the water has boiled away?

**2.** Why is it that so much more nutriment can be extracted from soup meats if the kettle in which they are boiled is kept tightly closed than if it is left open?

**3.** Why is one advised, in connection with large gas stoves, to open the door beneath the oven before lighting the oven?

**4.** With a water heater of 90 per cent efficiency, how many cubic feet of gas (calorific value, 600 B.T.U. per cubic foot) would be required to heat 50 gal. of water from 60° to 200° F., and what would be the cost of the gas at 80 cents per 1000 cu. ft.?

### TOPICS FOR FURTHER STUDY AND INVESTIGATION

Gas ranges; sizes, styles, and prices; installation; underwriters' rules.

Comparative cost of cooking by kerosene, denatured alcohol, gas, coal, and electricity.

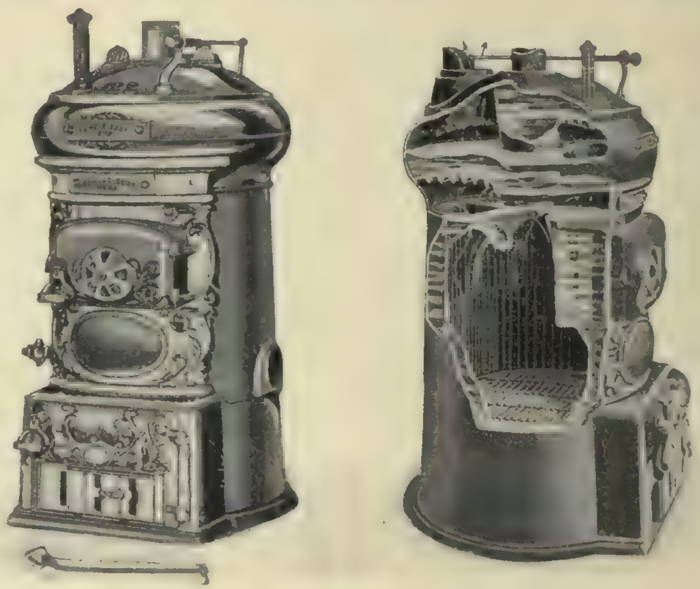
*Suggestion.* The cost per hour for the gas used in your own gas range may be determined as follows: Light the various burners, one at a time; stand beside the meter with watch in hand, and test the gas consumption in each case by noting the number of minutes required by the index hand in the small circle to make one complete revolution.

Rules to be observed for the sake of economy in cooking by gas.

Gas flatirons and gas heaters, and their effect upon the health of the user.

## 24. STUDY OF A DIAGRAM

### HEATING BY HOT WATER



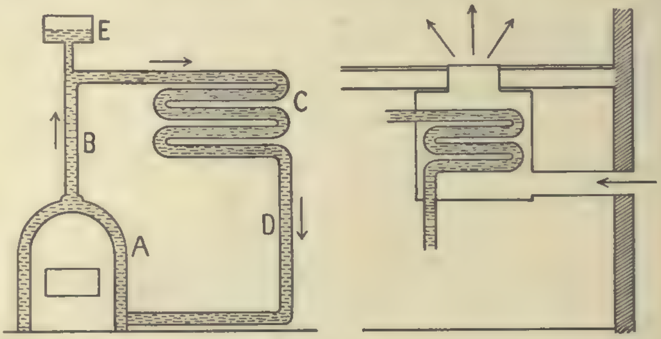
**Apparatus.** The diagram on page 51, showing a water boiler in place, with radiators, pipes, and connections as arranged for the heating of a small house or single apartment by the so-called direct system of hot-water heating; the diagram on page 52, showing practically the same apparatus as arranged for the heating of a similar house by the indirect system; a hot-water plant in actual operation, if one is to be found near by; commercial catalogues.

The illustration shows two views (exterior and interior) of a small boiler with attached thermometer and damper regulator; the arrows indicate the path of the hot gases through the flues.

#### INTRODUCTION

It is a curious fact that the amount of heat given out by a mass of hot water in cooling through a given number of degrees is far greater than that given out under similar conditions by any other known substance except liquid hydrogen. For this reason hot water in circulation should form an excellent substitute for hot air in the heating of houses. Its use is rapidly spreading. The principle underlying the apparatus employed is clearly shown in the following diagram:

*A* is a boiler, or "hot-water heater," of cast iron; *B*, a supply pipe running from the top of the boiler to a series of coils or to a radiator, *C*; *D*, a return pipe running from the radiator back to the boiler, which it reënters at the bottom. The entire system — boiler, pipes, and radiator — is completely filled with water. When the fire is lighted beneath the boiler, the water begins to circulate in the direction indicated by the arrows, for the same reason that the air circulates in connection with the hot-air furnace, a cubic foot of water at 39° F. being about 3 lb. heavier than the same volume of water at 212° F. The water is thus carried to the various rooms to be heated by the supply pipe, and is brought back to be heated over again by the return pipe as fast as it cools. The expansion of the water under the increase of heat is provided for by the expansion tank, *E*. The temperature of the house can be regulated, of course, by driving or checking the fire, since the rate of circulation of the water is thereby varied and the temperature of the water as well, but the response is considerably slower than with the hot-air furnace. Explain.



The scheme as outlined is known as the direct system of hot-water heating. It will be seen at once that, so far as ventilation is concerned, the system described presents no advantages over the far simpler plan of heating by stoves, since no provision is made for the renewal of the air, but only for the heating of it.

A modified plan known as the indirect system, possessing all the advantages of the hot-air furnace with respect to ventilation, is suggested by the figure at the right in the diagram on page 48. Each hot-water radiator is placed in a separate air duct leading from out of doors to the room to be heated, and in this position it acts like the fire box of a furnace, driving a continuous current of warm, fresh air into the house by convection. The foul air is allowed to escape through a fireplace opening into a chimney flue, or, in the absence of such a device, gradually leaks out through the doors and windows.

## EXERCISE

*Object.* To furnish practice in the interpretation of a diagram and to teach the main facts concerning the operation of a hot-water heating plant.

*Method.* 1. Write an article upon Heating by Hot Water, embodying, in any order you choose, correct answers to as many of the following questions as possible, the necessary information to be gathered from any of the following sources: the diagrams, commercial catalogues, the school engineer, your own experience.

The direct system. Why does the water move upward in the pipes when there is a fire in the furnace at *C*? How soon after the fire is lighted does the circulation begin? What is the use of the tank *O*? Why is the tank *O* placed in the attic? Is the tank *O* shown open or closed at the top? Explain. What is the use of pipe *I* and why is such a device necessary? Are all the water pipes of the same size? Why? What would be likely to happen if the fire were kindled at *C* when the water in the tank was frozen solid? What is the purpose of the valve *N*, and what precautions are to be observed in its use? How often during the year should the water be renewed? At what point is the fresh water introduced? What is the use of the clean-out door *B*? What would be the effect upon the circulation of the water if all the radiator valves above the first floor were closed? Do the rooms cool off rapidly or rather slowly after the water is shut off? Explain why it is that apartment houses are so apt to be overheated in winter. In the room upon the first floor at the right, what is the object of placing the radiator beneath the window? Why are not the hot-air registers of a hot-air furnace system similarly placed? It sometimes happens that a given radiator obstinately refuses to heat, although the water is apparently all turned on; suggest several possible causes, with remedies. What is to prevent a radiator, that is "all shut off," from freezing in very cold weather?

The indirect system. In what respects does this system differ from the direct system? Why are the hot-air registers placed near the outside walls? Why are not the hot-air registers used in connection with a hot-air furnace similarly placed? What is the advantage of having two valves at each radiator? What advantages has the sectional boiler over the solid one shown in the first diagram? What is meant by a fusible plug? Is any such device shown here? Why not? What are the advantages of the indirect system over the direct? What are its disadvantages?

What are the advantages of heating by hot water over heating by other methods?

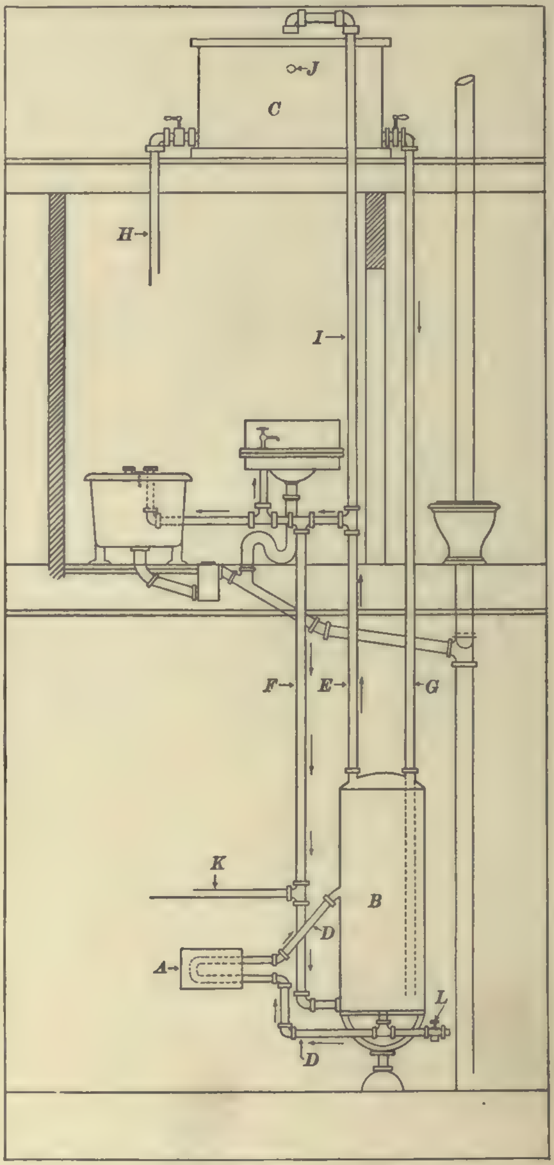
2. Secure a catalogue from the makers of the apparatus in your own home, if the house is heated by hot water, and write a very brief description of your home plant, illustrated by cuts from the catalogue.

## TOPICS FOR FURTHER STUDY AND INVESTIGATION

Hot-water supply.

The illustration, taken from a pamphlet published by the United States Department of Agriculture under the title *Modern Conveniences for the Farm Home*, shows the apparatus commonly installed in a modern house for the purpose of securing a continuous supply of hot water at the faucets in the bathroom, laundry, kitchen, etc.

*A* is the water front, placed inside the kitchen range and in front of the fire; *B*, the boiler; *C*, a tank in the attic; *D*, *E*, and *F*, hot-water circulation pipes; *G*, the boiler supply pipe; *H*, the cold-water pipe to tank and fixtures; *I*, the expansion pipe; *J*, the overflow pipe; *K*, a hot-water pipe to the kitchen sink; *L*, the drain cock.

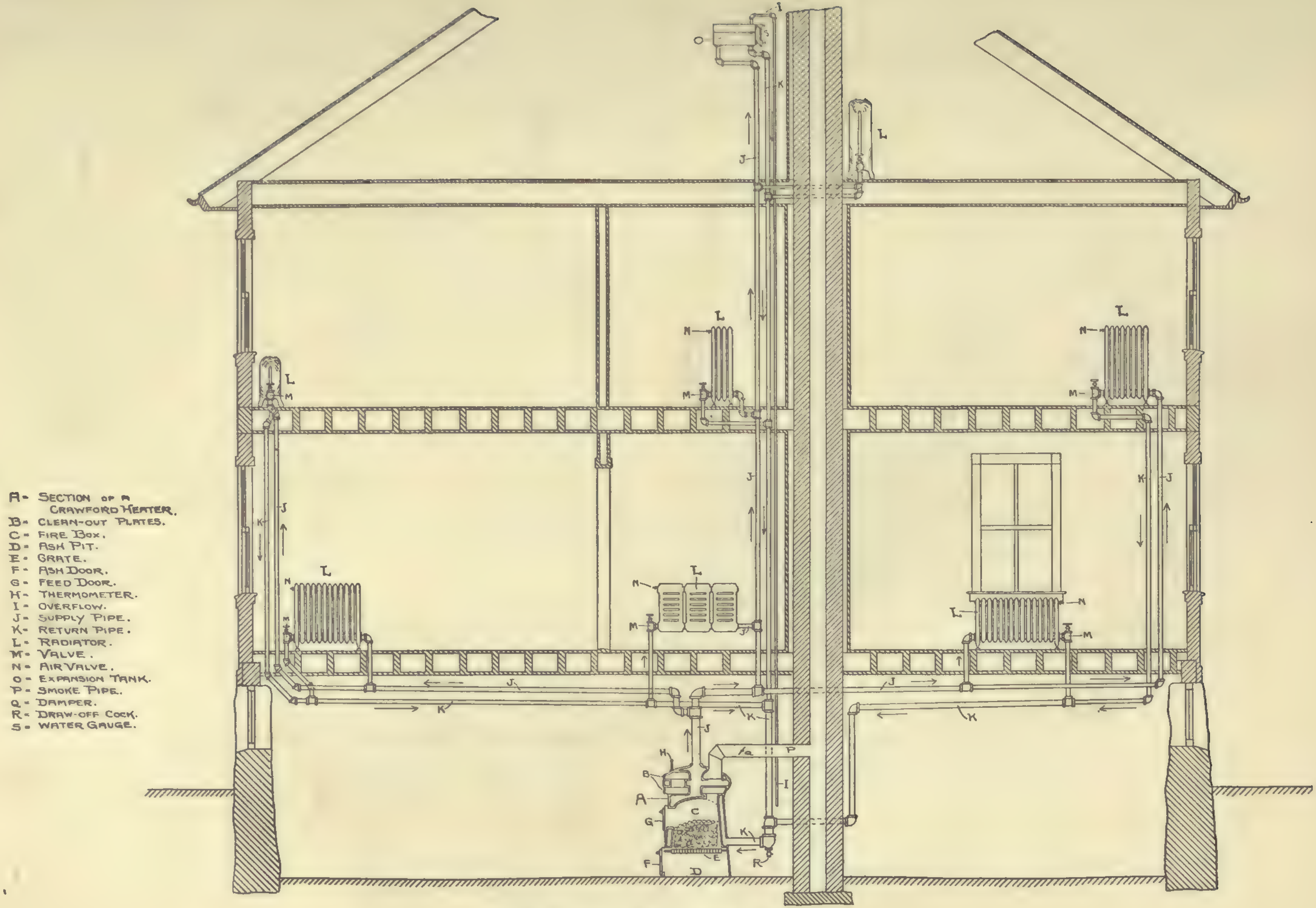


Show how the water in the boiler is heated by the fire in the range, describing the movement of the water in *D* and the path of the convection currents in *B*. Trace the circulation of the water in *E*, *F*, and *B*. Of what advantage to the bathroom is the pipe *F*? Why is the pipe *G* extended to the bottom of the boiler? What happens when steam is generated in the boiler? Does this often occur? Is there any danger? A kitchen in New England was recently wrecked by an explosion; an examination showed that the tank in the attic was frozen solid. Explain. A hot-water boiler sometimes collapses when the tank freezes and water is drawn from one of the lower faucets. Explain. It is advisable to draw off the water through the drain cock *L* occasionally. Why is this?

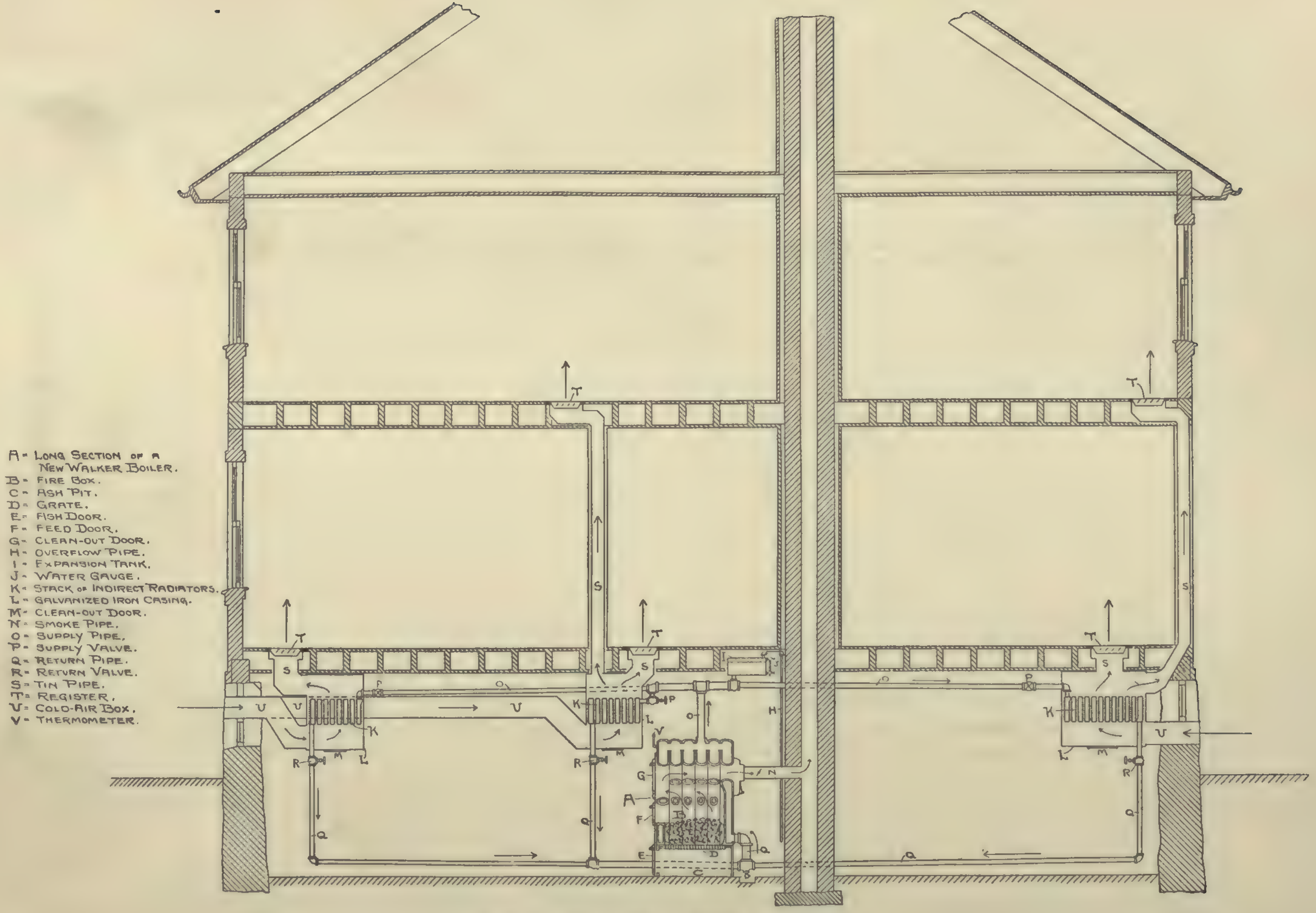
Examine your home plant, compare with the diagram, and report variations; look inside the tank, examine the device made use of to keep the water at a constant level, and explain its action. What material is used for the various pipes, the tank, and the boiler? Explain the choice of each.

Traps. It is required by law in many states that between every plumbing fixture and the cesspool or the sewer must be placed a trap with a "water seal," to prevent the poisonous sewer gas from entering the house through the drainpipe. Beneath the wash bowl (lavatory), in the illustration adjoining, is shown a trap of the simplest order, consisting merely of a downward bend in the drainpipe itself; the water caught and held in the pocket, or U-tube, thus formed, rising above the bend on either side, acts as a liquid plug (water seal) to hold back the sewer gas, while at the same time it allows the water, coming from the fixture above, to pass freely through the overflow on its way to the sewer. A trap of another form, known as the round trap, is shown beneath the bath tub. Each trap should be provided with a screw cap (placed beneath the water line of the trap) that may be unscrewed and taken off for the purpose of emptying the trap and for cleaning it. To prevent siphonage, or the sudden emptying of the trap by the rush of water in some other part of the system, the top of the trap or the outlet adjoining is often connected with a vent pipe (not shown in the illustration) leading to the roof. The trap is then said to be vented. Such an arrangement is required by law in some states.

Look up the traps in your own home. Are they easily accessible? Are they frequently flushed, by allowing a flood of water to flow through them, and are they cleaned out occasionally? Is there a trap at every fixture? Is each trap vented? Is the whole house trapped at the point where the sewer pipe leaves the house? What do the local plumbing laws require?



Direct Hot-Water Heating Apparatus



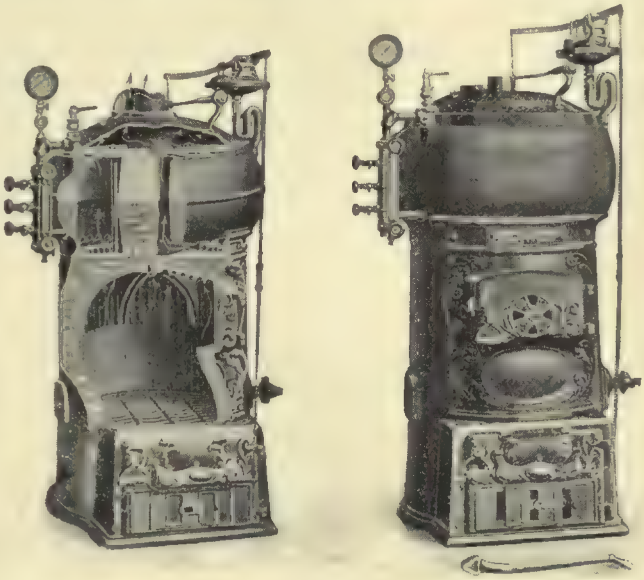
INDIRECT HOT-WATER HEATING APPARATUS

# 25. STUDY OF A DIAGRAM

## HEATING BY STEAM

**Apparatus.** The diagram on page 55, showing a steam boiler in place, with radiators, pipes, and connections as arranged for the heating of a small house or single apartment; a steam-heating plant in actual operation (this can probably be found either in your own home, in the school building itself, or in some church near at hand); commercial catalogues.

The illustration shows two views (interior and exterior) of a fire-tube steam boiler with safety valve, automatic damper regulator, gauge cocks, water glass, and pressure gauge.

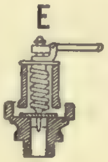


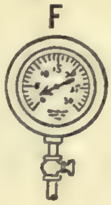
### INTRODUCTION

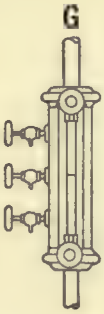
Careful experiments have shown that the amount of heat given out by a mass of steam at 212° F. in condensing to water at the same temperature is very nearly 967 times as great as that given out by the same amount of water in cooling through one degree Fahrenheit. This fact is expressed by saying that the latent heat of steam is 967.

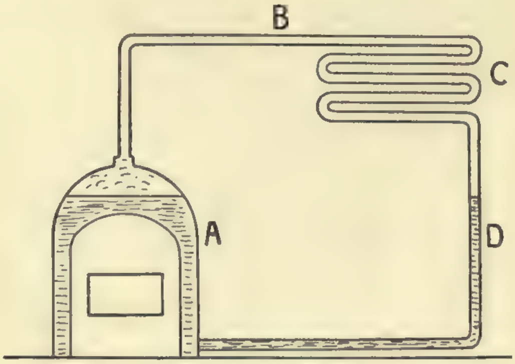
It is at once apparent that a small amount of steam may be made to convey a large amount of heat. Hence the frequent use of steam in the heating of our houses. The machinery employed is similar to that made use of in hot-water heating, but differs in some essential features.

*A* is a boiler two-thirds full of water; *B*, a supply pipe carrying live steam from the top of the boiler to the radiator *C*, at which point the steam is condensed and made to surrender its latent heat; *D*, a return pipe carrying the water formed from the steam condensed in the radiator back to the boiler to be heated over again. As live steam is constantly being generated in *A*, and condensed steam just as constantly returned through *D*, the action is continuous. The live steam, therefore, is made to serve as a conveyor of heat from the furnace to the room to be heated, precisely as the hot water was made to do in the preceding exercise.









Steam is a vapor, however, and not a liquid. If confined, its pressure increases rapidly with increase of temperature. A safety valve *E*, that lifts of its own accord against a weight or a spring when the pressure rises too high, and a steam gauge *F*, to serve as a warning to the engineer, are therefore placed upon every steam boiler to guard against accidents. A water glass and a number of gauge cocks *G*, to indicate the amount of water in the boiler at any given time, are provided as well.

## EXERCISE

*Object.* To furnish practice in the interpretation of a diagram and to teach the fundamental facts concerning the operation of a steam-heating plant.

*Method.* 1. Answer as many of the following questions as possible, the necessary information to be gathered from the diagram, from commercial catalogues, from some engineer in your vicinity, or from your own experience.

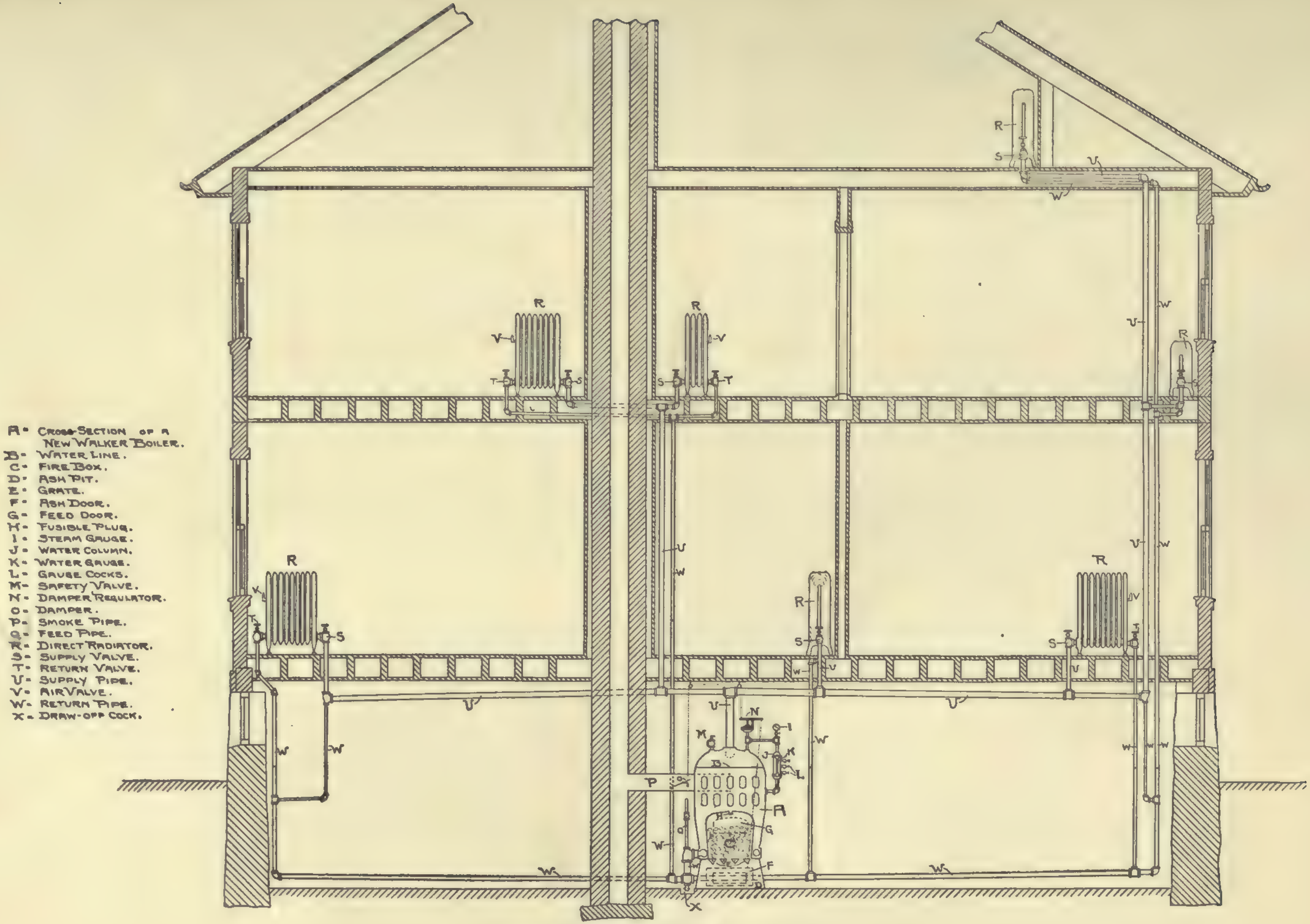
In what respects does the apparatus employed for steam heating differ from that made use of in a hot-water plant? What is meant by a sectional steam boiler? Describe the device marked *N* upon the diagram and explain its operation. Why are gauge cocks needed if the water glass answers the same purpose, and what are the rules to be observed in their use? What happens if the water glass breaks while steam is up, and what is to be done? What precautions are to be observed in the use of a safety valve? Describe the pop safety valve. What is a "police valve"? What pressure is usually carried upon a steam-heating plant? Describe the device marked *H* upon the diagram and explain its operation. Why are the supply pipes and the returns inclined to the horizontal in the basement? What would be likely to happen if a fire were built at *C* with the boiler empty, and, later, cold water were run into the boiler? What is the object of placing two stopcocks at each radiator? What is the purpose of the valve *V*? How is the valve *V* to be used? Steam-heating plants are often installed with supply pipe only. What becomes of the condensed steam in that case? What is the cause of the loud hammering sometimes heard in the pipes and radiators when the steam is first turned on? Suggest a remedy. It occasionally happens, in a small plant carrying steam at low pressure, that all the water will be found to leave the boiler suddenly. What is the probable cause? Is there any danger? What is to be done? Is the air of a room heated by a steam radiator any less dry on that account than the air in a room heated by hot water? Suggest several ways of adding moisture to the air. Is there any provision for ventilation shown in the diagram? Suggest several schemes. What are the advantages of heating by steam over heating by other methods? What are the disadvantages?

2. By tracing through tissue paper make a copy of the portion of the diagram showing the two rooms at the left upon the second floor, with the attic room above; complete the drawing to show a radiator in this attic, with the necessary connections.

3. Write an illustrated article of not less than five hundred words upon some one of the following topics:

Advantages of steam over hot water for house heating.
Various types of steam boilers.
Testing boilers for pressure. (The Massachusetts state law specifies 60 lb. per sq. in.)
The steam radiator.
Hammering in the radiator: its cause and cure
Automatic regulation of temperature.
Care of a water glass.
The safety valve.
Protection of steam pipes.
Kinds and sizes of coal, with relative heating values and cost per ton delivered at your own home. Number of tons consumed per month in heating an average house during winter weather.

4. Secure a catalogue from the makers of the apparatus used in your own home, if the house is heated by steam, and write a brief description of your own home plant, illustrated by the use of cuts from the catalogue.



Direct Steam-Heating Apparatus

## 26. STUDY OF MELTING ICE

### HEAT OF FUSION

**Apparatus.** A centigrade thermometer; calorimeter; platform balance; metric weights; cracked ice; a piece of cloth or a towel.

### INTRODUCTION

The cooling of the interior of a refrigerator by means of a block of ice (see illustration) is not unlike the heating of a closed room by means of a steam radiator, save that the action is reversed. Convection currents are established in the direction shown by the arrows, and the ice gradually melts, absorbing heat from the walls of the refrigerator, the foodstuffs, and the air in the process. The confined air accordingly grows steadily colder until the amount of heat that is absorbed by the ice in melting is just balanced by the amount that leaks in through the walls and the door of the refrigerator; equilibrium is then established and the temperature becomes constant. For the sake of economy in the use of ice, and to insure the maintenance of a correct temperature (about 50° F.) in the refrigerator, the walls of the refrigerator are made double and the space between is filled with some good nonconductor of heat, such as magnesia, powdered cork, or sawdust.

*Definition.* The number of calories required to melt a gram of ice at 0° C., or the number of British Thermal Units (B.T.U.) required to melt a pound of ice at 32° F., is called the *heat of fusion* of ice.

The amount of heat given out by any substance in cooling equals specific heat × weight × change in temperature. The specific heat of the material of the calorimeter is .1.

### EXERCISE

*Object.* To determine the heat of fusion of ice.

*Method.* Find the weight of the calorimeter in grams and record under *Data* (see *Form of Record*). Fill the calorimeter two-thirds full of water at a temperature of about 60° C. and weigh again; determine the weight of water, and record.

Break the ice into pieces about half the size of a hen's egg.

Stir the water in the calorimeter thoroughly with the thermometer; determine its temperature precisely and record as the initial temperature of the water. Dry three or four pieces of ice quickly with the towel and drop them into the calorimeter; stir the water with the thermometer until the last bit of ice is about to disappear; then, just as the last piece melts, determine the temperature to a tenth of one degree and record as the final temperature of the water.

While the ice is melting do not hold the calorimeter in the hands nor breathe upon it.

Finally, to determine the weight of ice used, weigh the calorimeter with its contents once more, and record.

The heat given out by the water and the calorimeter in cooling was used in part to melt the ice and in part to raise the temperature of the ice water (melted ice) from 0° C. to the temperature of the mixture. To determine the amount of heat required to melt the ice we must therefore compute the number of calories given out by the water and the calorimeter (see Study of a Solid: Specific Heat) and compute the number of calories used in raising the temperature of the ice water from 0° C. to the final temperature; the difference will be the number of calories used in melting the ice.

Complete the tabular statement.

*(Form of Record)*

## STUDY OF MELTING ICE

### Heat of Fusion

*Data*

Weight of calorimeter .......... g.
Weight of calorimeter and water .......... g.
Weight of water .......... g.
Initial temperature of water .......... °C.
Final temperature of water (*t*) .......... °C.
Weight of calorimeter, water, and ice .......... °C.

*Computations*

Weight of ice (*w*) .......... g.
Drop in temperature of water and calorimeter .......... °C.
Calories given out by water and calorimeter (*c*) ..........
Rise in temperature of ice water ($t - 0$) .......... °C.
Calories used in warming the ice water ($c'$) or ($w \times t$) ..........
Calories used in melting the ice ($c - c'$) ..........
Calories used in melting 1 g. of ice ..........

*Conclusion*

The heat of fusion of ice is ..........

Accepted value, 80 calories per gram, or 147 B.T.U. per pound.

## PROBLEMS

**1.** How many calories of heat are absorbed by 50 g. of ice in melting? How many calories of heat are given out by 200 g. of ice in freezing?

**2.** How many calories of heat are required to melt 300 g. of ice at 0° C. and heat it to 25° C.?

**3.** How many British Thermal Units are absorbed by 50 lb. of ice in melting?

**4.** A farmer puts into his cellar a tub containing 16 gal. of water at 62° F. How much heat will this water give out into the cellar before it is all frozen? What effect will the freezing of the water have on the temperature of the cellar?

**5.** Why does the ice in a refrigerator continue to melt after everything but the ice has been taken out?

**6.** How many extra pounds of ice must be melted in a refrigerator in order to cool 10 lb. of butter (specific heat, .5 B.T.U. per pound) 20 degrees?

**7.** How many pounds of ice are needed to cool a bucket of water (16 lb.) from 70° to 40° F. if the ice is put directly into the water?

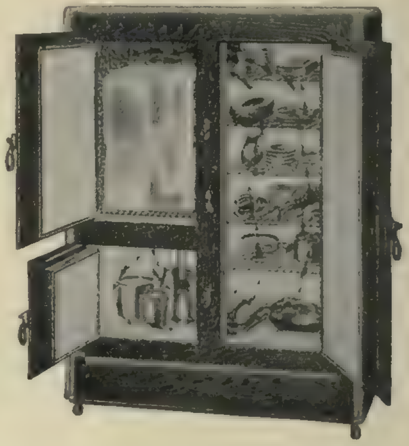
## TOPICS FOR FURTHER STUDY AND INVESTIGATION

Household refrigerators — sizes, styles, and prices. See advertisements in current household magazines and commercial catalogues.

A first-class refrigerator may be expected to maintain in its central food compartment an average temperature of about 47° F. when the outside temperature is from 68° to 70° F., and a temperature of 54° F. when the outside temperature is in the neighborhood of 90° F. The ice consumption varies greatly with the location and care of the refrigerator; in a city apartment and for a refrigerator whose ice capacity is from 75 to 90 lb. it may be expected to average from 30 to 40 lb. per day.

The interior of the refrigerator should be kept clean and dry; the drainpipe should be provided with a water-seal trap to prevent the entrance of hot air, insects, and odors from outside, and the entire drainage system should be emptied and cleaned at least once a week. An unsanitary refrigerator is a distinct menace to the health of the family.

An ideal arrangement for the storage of the food supplies in a side-iced refrigerator is shown in the illustration. Milk, butter, and other foods equally easy to contaminate are placed directly beneath the ice compartment; on the right, below the level of the ice compartment, are the meats, above are the vegetables, and at the top are the fruit, berries, and other foods of strong odors and flavors. The theory underlying this arrangement may be expressed as follows: When the air in circulation reaches the ice, condensation takes place, the moisture absorbed from the foodstuffs is deposited, the odors are carried off through the drainpipes, and the cooled air enters upon its next journey through the refrigerator as dry and pure as at the start.



By the use of an ordinary household thermometer and a quart measure or a balance, test the refrigerator in your own home as to the temperature maintained in its food compartments and the daily consumption of ice. (In testing for temperature, place the thermometer in the center of the food compartment, keep the refrigerator closed for at least an hour, and observe the temperature immediately after opening the door.) Compare results with those obtained by other members of the class.

*Freezing mixtures.* Fill a large tumbler or a calorimeter two-thirds full with a mixture of shaved ice, or snow, and salt (three parts by weight of ice to one of salt); stir the mixture thoroughly with the thermometer and record the temperature at its lowest point; place a test tube half full of water upright in the mixture; insert a thermometer in the test tube and note the temperature as the water freezes. (A mixture of ten parts of crystalline calcium chloride with seven parts of snow gives a temperature of – 66.8° F., and mercury is frozen solid.)

Explain the action of an ice-cream freezer.

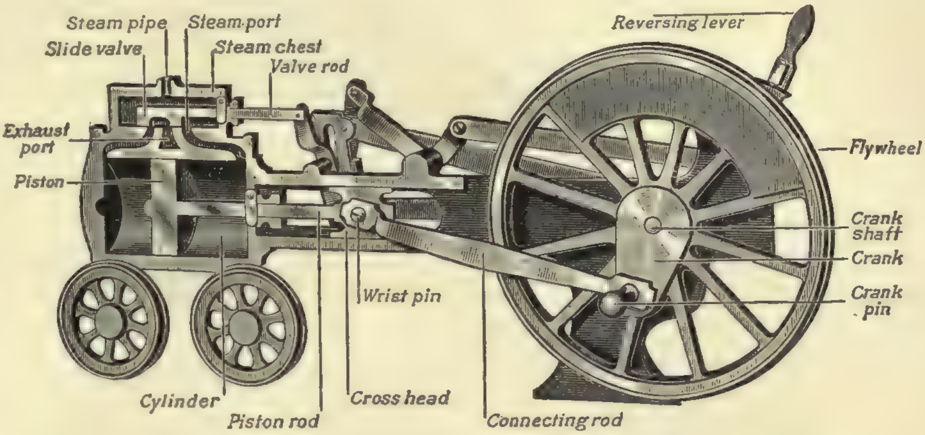
# 27. STUDY OF A HEAT ENGINE

## THE STEAM ENGINE

**Apparatus.** A working model of a locomotive engine, showing the cylinder and steam chest in section with the piston and slide valve in place and the parts properly connected.

### INTRODUCTION

One of the most important agencies employed in the development and spread of civilization during the last hundred years has been the steam engine of the type developed by James Watt in the early part of the nineteenth century; mechanical industries of every sort, including the printing of books and newspapers and their transportation over land and sea, have been largely dependent during all these years upon the power of steam.



The action of a steam engine can be readily understood from a study of the model. Live steam, under pressure from the boiler, is admitted to the steam chest through the steam pipe (see illustration) and is compelled, through the shifting of the slide valve, to enter first one end of the cylinder and then the other in regular succession. A to-and-fro (reciprocating) motion is thus imparted to the piston, and the flywheel is made to rotate exactly as the flywheel of a lathe or a sewing machine is made to revolve by the up-and-down motion of the foot upon the treadle. The spent steam in the dead end of the cylinder escapes to the outer air through the interior of the slide valve, the exhaust port, and the exhaust pipe (not shown) at the rear.

### EXERCISE

*Object.* To study the movement of the piston and the slide valve in a locomotive engine.

*Method.* 1. Rotate the flywheel until the crank pin is brought into a position exactly over the end of the crank shaft. Make a careful drawing of the steam chest and cylinder, with the slide valve and piston in place as they now stand; indicate the movement of the piston, and of the steam at either end of the cylinder, by arrows, and explain the diagram. Is the locomotive moving forward or backward?

2. Continue the rotation of the flywheel, in the direction indicated by the position of the slide valve, through 90°, and discuss as before.

3. Continue the rotation through 90° and discuss as before.

4. Complete the cycle, bringing the flywheel back to the position indicated in paragraph 1. Finally, turn the flywheel slowly through one complete revolution; observe carefully the entire movement of piston and slide valve, and in a special note comment upon anything that strikes you as worth referring to.

5. Push the reversing lever over; rotate the flywheel once more and explain why the engine would now run in the opposite direction.

6. Turn the model around; examine the eccentric that moves the slide valve and explain its action, together with that of the reversing lever.

### PROBLEMS

**1.** What is the cause of the heavy puffing of the locomotive when a heavily loaded train is being drawn up a steep grade?

**2.** Why does the engineer, when starting a steam engine, often allow a small quantity of steam to escape, through a stopcock provided for the purpose, from each end of the cylinder?

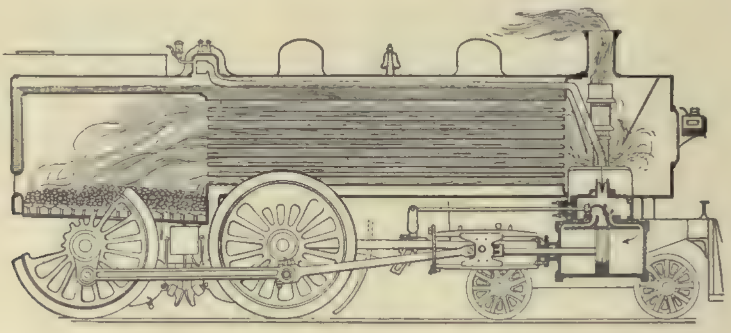
**3.** Why does a locomotive sometimes blow off steam when standing at a railway station?

**4.** What is the cause of the throbbing sound often heard near the cab of the locomotive when a railway train is standing at a station?

**5.** The diameter of the piston of a steam engine is 10 in. and the length of its stroke is 1.5 ft.; the average pressure of the steam in the cylinder is 100 lb. per sq. in. What is the total pressure exerted on the piston? How much work (in ft.-lb.) is done at each revolution of the flywheel? What is the indicated horse power of the engine if the flywheel makes 300 revolutions per minute?

### TOPICS FOR FURTHER STUDY AND INVESTIGATION

The locomotive boiler. The illustration shows a *fire-tube* boiler of the usual type. The hot gases from the fire box pass through a series of metal tubes, which are surrounded by the water in the boiler, to the smokestack, while the dry steam accumulates in the steam dome at the top of the boiler and from that point is conveyed through a steam pipe, fitted with a valve, or throttle, under the control of the engineer, to the cylinders below.



Setting the slide valve.

High-pressure and low-pressure engines.

Compound engines.

Steam turbines.

The gas engine.

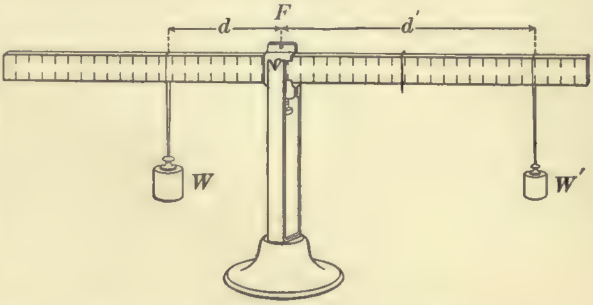
## 28. STUDY OF A LEVER

### PRINCIPLE OF MOMENTS

**Apparatus.** Meter stick; knife-edge clamp and support; metric weights.

#### INTRODUCTION

"Give me a place to stand and I will move the earth," said the great philosopher Archimedes, while investigating the principle of the lever, more than two thousand years ago. And in truth, with a lever long enough and the pivot in the right place, a pound weight can be made to lift unnumbered tons. Six simple machines — the lever, the wheel and axle, the pulley, the inclined plane, the wedge, and the screw — gave early man his supremacy over the forces of nature, and these same simple machines are to-day the principal elements in all modern machinery.



A lever, in its simplest form, may be represented by a bar so mounted as to be capable of turning about a pivot or a fulcrum. The word *moment*, as used in this exercise, denotes the turning effect of a force about a pivot (a weight about a fulcrum) and is equivalent to the product of the force and the perpendicular distance from the pivot to the line of direction of the force. A moment is called negative when it tends to produce rotation in the same direction as the hands of a clock, and positive when it tends to produce rotation in the opposite direction. Thus, $W' \times d'$ (see illustration) is the moment of the weight $W'$ about the fulcrum $F$ and is to be recorded as negative ($-$).

The point about which a body balances is called the center of gravity of the body. Locate the center of gravity of a parallelogram, of an isosceles triangle, of a circle, of a cylinder, and of a sphere.

#### EXERCISE

*Object.* To investigate the action of a lever and to test the principle of moments.

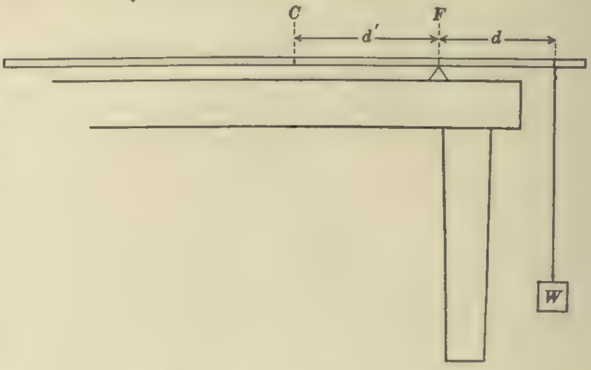
*Method.* Slip the clamp over one end of the meter stick and slide it along to the center; secure the clamp firmly in place by means of the thumbscrew and mount the whole upon the support as shown in the illustration above. If under these conditions the lever does not balance exactly, hang a rider, in the form of a bent wire or a small saddle of some heavy material, over the bar upon the lighter side; push it along until the lever is horizontal, and pinch it firmly in place.

1. By means of a thread suspend a known weight $W$ (see illustration) from a point at some distance to the left of the fulcrum $F$ and hang another known weight $W'$, of a different amount, at the right of the fulcrum; move the second weight along the meter stick until the lever balances; determine $d$ and $d'$, the distance from the fulcrum to the thread in each case, and compute the moment of each weight about the fulcrum. Compare positive and negative moments. Make five trials, using different distances. Record in tabular form. Conclusion?

Hang two weights at the right of the fulcrum and two at the left; balance the lever. Compare the sum of the positive moments with the sum of the negative moments. Conclusion?

Hang an unknown weight (a block of wood or a textbook) on one side of the lever and a known weight on the other, and determine the weight of the unknown from the law of moments. Test the result by means of a spring balance.

2. Find the center of gravity $C$ of a meter stick by balancing the stick over the edge of a prism lying on the table; hang a known weight $W$ from a point near one end of the meter stick (see illustration) and balance it by moving the stick along over the edge of the prism; measure $d$ and $d'$.



Imagine a weight $X$, of unknown value, acting at $C$, the center of gravity of the lever, and let this unknown weight represent the force (due to the weight of the lever) at the left of the fulcrum, that is balancing the weight $W$ at the right. Then, by the principle of moments, $W \times d = X \times d'$. Substitute values of known quantities and compute the value of $X$ (the force exerted by the lever at $C$). Repeat the experiment several times, using different weights in place of $W$.

Weigh the meter stick and compare with the value obtained for $X$ in each case. Conclusion? Tabulate results as follows:

| $W$ | $d$ | $d'$ | $X = \frac{W \times d}{d'}$ |
|---|---|---|---|
| | | | |

Weight of the lever..................................................................................................

*Conclusion*

## PROBLEMS

**1.** A lever is supported at its center of gravity; a weight of 25 lb. on one side of the fulcrum is balanced by a weight of 100 lb. on the other. If the first weight is 8 ft. from the fulcrum, how far away is the second?

**2.** Show by a diagram an arrangement by which 3 lb. may be made to lift 15 lb.

**3.** A crowbar is 5 ft. long. Where must the fulcrum be placed that a man weighing 200 lb. may be able to pry up a rock weighing 1000 lb. by throwing his entire weight upon the handle end of the bar? Neglect the weight of the bar.

**4.** The handles of a pair of tinsmith's shears are 24 in. long, and the article to be cut is placed between the jaws at a distance of 2 in. from the pivot. How great a cutting force can be produced by a pressure of 50 lb. applied at the end of the handles?

**5.** A man and a boy carry a load of 300 lb. between them on a uniform pole weighing 30 lb. Where must the load be placed in order that the man may carry 240 lb. and the boy 90 lb.?

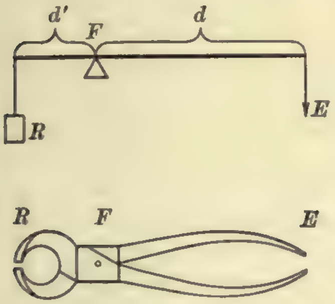
**6.** Suppose the weight of the meter stick in the illustration is 85 g.; $d$, 15 cm.; and $d'$, 20 cm. What is the amount of the weight $W$?

**7.** Show by a diagram how the weight of a fish may be found by means of a walking stick of known weight and a foot rule.

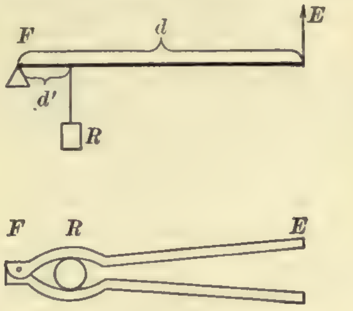
**8.** A uniform bar $AB$, 12 ft. long and weighing 20 lb., is supported on a fulcrum $C$ placed 3 ft. from the end $A$; a weight of 30 lb. is hung at $A$ and a weight of 2 lb. at $B$. Where must a weight of 3 lb. be placed to produce equilibrium?

**9.** Make a diagram, drawn to scale, of a pair of cutting pliers designed to produce a cutting force of 500 lb. under the pressure of your own grip.

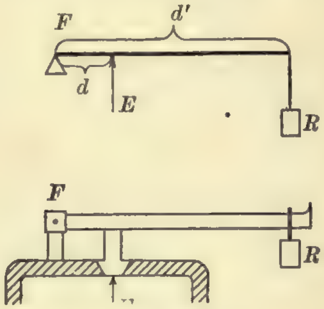
Classes of levers. For the sake of convenience in discussion the various forms of levers in practical use may be divided into three classes, according to the relative position of effort $E$ (force applied), fulcrum $F$, and resistance $R$, as shown in the illustration. In each case $E \times d = R \times d'$. $R/E$ (mechanical advantage, or leverage) $= d/d'$.



First class



Second class



Third class

Bent levers.

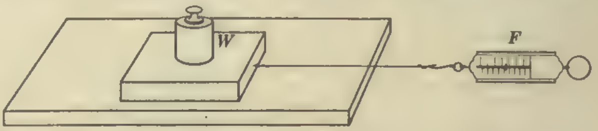
Report as many appliances making use of the principle of the lever as you can find about the house or the laboratory, and determine the classification of each; make the necessary measurements and compute the mechanical advantage in each case.

## 29. STUDY OF A SLIDING BODY

### FRICTION

**Apparatus.** A rectangular block of pine or other convenient material, with sides well planed; smooth board of the same material as the block; set of weights; spring balance.

### INTRODUCTION



In the use of machines to do work we are continually met by friction, or the resistance encountered whenever an attempt is made to slide one surface over another. Work done against friction is usually converted into heat and wasted in radiation.

The amount of friction between two surfaces in contact depends upon the nature of the surfaces and the pressure between them. The ratio $F/W$ between the force $F$ required to cause sliding and the perpendicular pressure $W$ between the surfaces in contact is called the coefficient of friction $k$. $F/W = k$.

### EXERCISE

*Object.* To determine the coefficient of friction of pine on pine.

*Method.* Find the weight of the block by means of the spring balance. Lay the block on the board and place a weight on top of it. By means of a thread attach the hook of the balance to the screw eye in the end of the block, and with the balance held horizontally draw the block slowly and steadily along the board. The average reading of the balance measures the amount of friction. Record. The total weight resting on the surface of the board, including the weight of the block and its load, represents the pressure. Record. Compute the coefficient of friction. Make five trials, using widely varying loads up to the capacity of the balance; determine the coefficient in each case and record the average as the coefficient of pine on pine. Is the coefficient at the instant of starting the same as the coefficient when the body is sliding steadily?

Report in tabular form.

### PROBLEMS

1. What are some of the uses of friction?

2. If it requires a force of 100 lb. to draw a sled weighing 600 lb. over the ice, what is the coefficient of friction?

3. If the coefficient of friction on a level railway is .004, how much force per ton of weight must be exerted by the locomotive in order to draw a train of cars along the track?

### TOPICS FOR FURTHER STUDY AND INVESTIGATION

Coefficient of friction for the various metals in common use.

Coefficient of rolling friction. Place a number of lead pencils under the block; use a heavy load and try to find the coefficient of rolling friction in this case. How does it compare with the coefficient of sliding friction?

Ball bearings; cylindrical bearings.

Lubricants for special purposes.

Angle of repose for sand, sugar, salt, etc.

Advantages and disadvantages of friction.

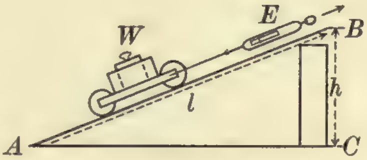
## 30. STUDY OF AN INCLINED PLANE AND A SCREW

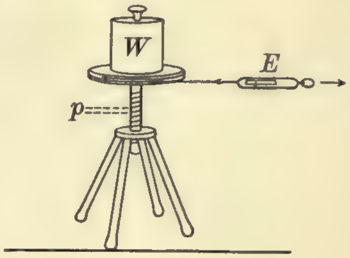
### EFFICIENCY

**Apparatus.** (1) A smooth board supported at one end; small car; spring balance; cord; set of weights. (2) An office stool arranged to screw up and down, or a commercial jackscrew having a grooved wheel in place of the usual lever; spring balance; cord; weight to be lifted.

### INTRODUCTION

*Work* equals *force* times *distance* and is usually expressed in foot pounds or kilogram-meters; small amounts of work may be expressed in gram-centimeters.





Under ideal conditions the work delivered by a machine (output) equals the work put into it (input). These conditions are never met in practice. A certain amount of work is always wasted in friction. Output, therefore, is always less than input. Efficiency equals $\frac{\text{output}}{\text{input}}$.

The force applied is called the effort. By the pitch of a screw is meant the distance between threads.

### EXERCISE

*Object.* To determine the efficiency of a given inclined plane, and of a screw, under widely varying conditions.

*Method.* 1. *The inclined plane.* Measure the height $h$ (see illustration) of the inclined plane and its length $l$. Place a weight of 200 g. or more in the car. Determine the *weight* $W$ of the *loaded car* by means of the spring balance.

Arrange the apparatus as in the illustration. Find the force $E$ (effort) required to draw the loaded car steadily up the incline. Record.

The output is equal, clearly, to $W \times h$, since the purpose of the machine is to lift the loaded car up the height $h$. What is the input? What is the efficiency?

Make several trials, using different loads. Does the efficiency vary? Why? How would the efficiency be affected if the car were not counted as a part of the load? Should it be so counted in practice?

Turn the car upside down and fasten a weight on it; determine the effort required to drag the loaded car up the incline under these conditions and compute the efficiency.

The law of the inclined plane may be determined as follows: In the ideal machine, output = input. Therefore $W \times h = E \times l$, or the weight to be lifted times the height of the inclined plane equals the effort times the length of the inclined plane.

The mechanical advantage $\left(\frac{W}{E}\right)$ of the ideal machine equals $\frac{l}{h}$.

Complete the tabular statement (see *Form of Record*).

2. *The screw.* Measure the diameter of the *head* of the stool, hereafter called the wheel, and compute the circumference $C$ in feet. Measure the pitch, $p$, of the screw in inches, and express the result in feet. Place a heavy load $W$ (150–200 lb. if possible) on the top of the stool. Determine the force $E$ required to move the weight slowly and steadily upward by pulling on the spring balance and revolving the wheel as the cord unwinds from the rim. How far is the weight lifted at each

revolution of the wheel? What, then, is the output? How far does the hook of the spring balance move? What is the input? What is the efficiency of the apparatus? Make several trials, using widely varying weights. How do you account for the low efficiency of the machine? How could the efficiency be increased?

What is the law of the screw (the ideal machine, in which output equals input)? What is the mechanical advantage $\left(\frac{C}{p}\right)$ of this particular machine?

(*Form of Record*)

### STUDY OF AN INCLINED PLANE AND A SCREW

### Efficiency

(Sketch)

1. **Inclined Plane**

| *Data* | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Height ($h$) | | | | | |
| Length ($l$) | | | | | |
| Total weight lifted ($W$) | | | | | |
| Effort ($E$) | | | | | |
| *Computations and conclusions* | | | | | |
| Output ($W \times h$) | | | | | |
| Input ($E \times l$) | | | | | |
| Efficiency (%) | | | | | |

Mechanical advantage .................................... Law of the inclined plane ....................................

Comments

(Sketch)

2. **Jackscrew**

| *Data* | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Diameter of wheel | | | | | |
| Circumference ($C$) | | | | | |
| Load ($W$) | | | | | |
| Effort ($E$) | | | | | |
| Pitch of screw ($p$) | | | | | |
| *Computations and conclusions* | | | | | |
| Output ($W \times p$) | | | | | |
| Input ($E \times C$) | | | | | |
| Efficiency (%) | | | | | |

Mechanical advantage .................................... Law of the screw ....................................

Comments

### PROBLEMS

**1.** What is the law of the inclined plane? What is the law of the screw?

**2.** A boy who can exert a force of 50 lb. wishes to roll a barrel of flour (150 lb.) up into a wagon body that is 3 ft. above the ground. What is the shortest plank that can be used to accomplish the purpose? How many foot pounds of work must the boy do?

**3.** What force will be required to push an automobile weighing 1 ton up a 10 per cent grade (rising 10 ft. for every 100 ft. of length), friction being neglected? What horse power would be required to drive the automobile up the above grade at the rate of four miles an hour?

**4.** Mention some useful applications of the screw.

**5.** In a letter press the diameter of the handwheel is 12 in. and the pitch of the screw $\frac{1}{4}$ in. What pressure will be exerted by a force of 100 lb. applied at the rim of the wheel if 60 per cent of the force is wasted in friction? What is the efficiency of the machine? What is its mechanical advantage?

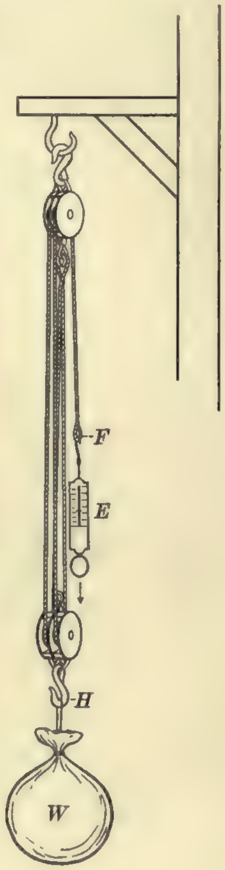
## 31. STUDY OF A BLOCK AND TACKLE

### EFFICIENCY

**Apparatus.** Block and tackle (commercial form, yacht size); set of weights (blocks of iron or bags of sand); spring balance; yardstick.

### INTRODUCTION

In nautical language a pulley is a *block*; the wheels are *sheaves*; a combination of pulleys connected by a cord is a *block and tackle.* A movable pulley is one that moves with the weight.



The illustration shows a block and tackle made up with two double blocks. The weight (including the movable pulley) is supported by four strands, and each strand carries one fourth of the load; one of the strands is held by the spring balance. A pound weight applied at $F$ will lift nearly four pounds at $H$ (why not exactly four pounds?); the effort moves four times as far as the resistance, and the mechanical advantage is 4.

Design an arrangement of pulleys in which the mechanical advantage shall be 2; design another in which it shall be 3.

### EXERCISE

*Object.* To determine the efficiency of a given block and tackle under various loads.

*Method.* 1. Suspend the block and tackle from a bracket on the wall (see illustration) and hang a weight on the lower block. Count the number of strands supporting the movable pulley. Through how many feet must the effort be exerted to lift the weight (resistance) one foot? Verify by actual measurement.

2. Hang a weight of 10 lb. on the lower block and determine, by use of the spring balance, the effort $E$ required to raise the weight $W$ at a uniform speed. Compute the input (work done by the effort), the output (work done on the load), and the efficiency, for a lift of 3 ft. In determining the useful output, should the weight of the movable pulley be reckoned as a part of the load? Why?

Make several trials, using weights of 10, 20, 30, and 50 lb. Is the efficiency a constant? Explain.

Illustrate your report by a diagram showing the arrangement of the rope and the sheaves.

*(Form of Record)*

STUDY OF A BLOCK AND TACKLE: EFFICIENCY

*Data*

Number of strands supporting movable pulley..............................

| Trials | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Effort ($E$) | | | | |
| Weight ($W$) | | | | |
| Effort-distance | | | | |
| Weight-distance | 3 ft. | 3 ft. | 3 ft. | 3 ft. |
| *Computations and conclusions* | | | | |
| Input | | | | |
| Output | | | | |
| Efficiency (%) | | | | |

## PROBLEMS

**1**. Sketch an arrangement of fixed and movable pulleys by which 160 lb. shall be able to support 480 lb.

**2**. What is the smallest number of sheaves that may be used in the movable pulley of a block and tackle if a force of 100 lb. is to lift a weight of 600 lb.? What is the law of the pulley?

**3**. The efficiency of a given block and tackle is 65 per cent; there are two sheaves in each block. What weight can be raised by the effort of three men whose combined weight is 550 lb.?

## TOPICS FOR FURTHER STUDY AND INVESTIGATION

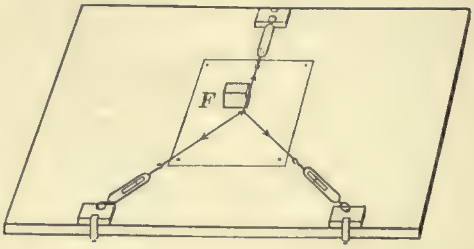
Look up in the dictionary, or in an encyclopedia, the definition of each of the following nautical terms, and report: Snatch block, fiddle block, strap, swivel hook, match hooks, becket, thimble, luff tackle, gun tackle, runner and tackle, Spanish burton.

Learn to make as many of the following knots as possible: Overhand knot, square knot, slip or halter knot, bowline, clove hitch, timber hitch, Blackwall hitch, two half hitches, the fisherman's knot, carrick bend, cat's paw. (See dictionary, encyclopedia, or Boy Scout's Handbook.)

## 32. STUDY OF CONCURRENT FORCES

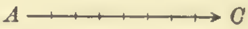
### PARALLELOGRAM LAW

**Apparatus.** Three spring balances; four small rectangular blocks, one a little larger than the rest; three clamps; cord.

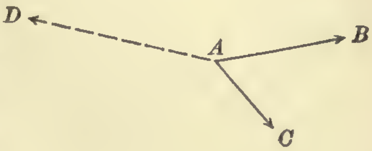


### INTRODUCTION

In dealing with a number of forces whose lines of direction meet at a point (concurrent forces) it is often found convenient to represent each of the several forces by a straight line drawn to scale, the direction of the force being indicated by the direction of the line, and the magnitude of the force by the length of the line. Thus, the line *AC*, eight units in length, represents a force of 8 g. (or 8 lb. or 8 T.) acting at the point *A* and in the direction *AC*. The unit of measure may be of any convenient length.



Two forces whose lines of direction, *AB* and *AC*, form an oblique angle with one another cannot possibly produce equilibrium, as will be apparent from the figure; a third force *AD* acting in an entirely different direction must be added to counteract the effect of the other two.



To determine the relations existing among three concurrent forces in any given case of equilibrium is the purpose of this exercise.

### EXERCISE

*Object.* To determine the conditions under which three concurrent forces will produce equilibrium.

*Method.* Connect the hooks of the balances by three cords knotted together as in the illustration. Hook the ring of each balance over a nail driven into one of the small blocks, and clamp the blocks to the edges of the table.

Adjust the apparatus in such a manner that each balance shall be stretched, by the pull of the cords, to at least one half of its full length, and secure the blocks firmly in place.

Lay a sheet of paper on the table under the cords and secure it in place with thumb tacks or weights.

Place the rectangular block *F* beside each of the three cords in turn, as in the illustration, and with a sharp pencil draw a line on the paper along the edge of the block, to show the direction of each of the three cords. Record on each line the force represented by the reading of the adjacent balance, and remove the paper.

Extend the lines until they meet; from the meeting point, and with any convenient scale ($\frac{1}{4}$ in. = 1 lb.), lay off distances on the several lines proportional to the corresponding forces; place an arrowhead at the end of each distance and erase the rest of the line. These lines represent, in magnitude and direction, the three concurrent forces under investigation. Construct a parallelogram upon any two of the forces as sides and draw the diagonal from the meeting point; place an arrowhead at the outer end of the diagonal; measure the length of the diagonal and express the result in pounds. This diagonal represents the resultant (combined effect) of the two forces which form the adjacent sides of the parallelogram.

How does the resultant compare in magnitude and direction with the third force (the equilibrant)? How is the resultant related to the two component forces?

Write up the exercise in good form, and report with a copy of the diagram; indicate the original forces by heavy lines and make the auxiliary lines dotted.

## PROBLEMS

**1.** Two tugboats are pulling on a vessel, one with a force of 1200 lb. and the other with a force of 900 lb. The cables from the two tugs are at right angles to each other. How much is the resultant pull on the vessel?

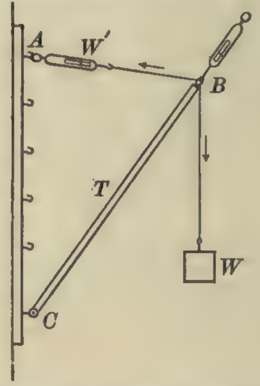
**2.** A weight of 100 lb. is suspended in the air by two cords that make an angle of 60° with each other. Determine the tension of each cord.

**3.** A skiff is driven by the force of the wind in the direction due north at the rate of 20 mi. an hour and by the force of the tide in the direction due east at the rate of 10 mi. an hour. Draw a diagram. In what direction will the boat actually move, and at what rate in miles per hour?

## TOPICS FOR FURTHER STUDY AND INVESTIGATION

The crane boom or stick and tie.

The illustration shows a model boom or strut consisting of a light stick pivoted, by means of a pin and a pair of screw eyes, at one end *C* and carrying a weight *W* suspended at the other end *B*. The boom is held in place by a cord, or guy, *AB* fastened to a hook in the wall. A spring balance is inserted in the line *AB* to measure the tension of the cord.



To determine the force tending to compress the stick in the direction *BC*, proceed as follows: By means of a large protractor measure the angle *ABW*; construct a parallelogram of forces with the forces *W* and *W′* as sides and determine the value of the resultant in pounds. Check your result as follows: Attach a spring balance to the end of the strut at *B*, and by a steady pull in the direction *CB* determine the force required to barely lift the strut from the pivot; compare the force represented by the reading of the balance with the value of the resultant obtained from the diagram. Repeat the experiment with a stick supported in a horizontal position.

With the stick in its original position, measure the angles *ABC* and *CBW*; note the value of the weight *W*; construct the parallelogram of forces and determine, by construction, the force *W′*. Check your result by the reading of the balance.

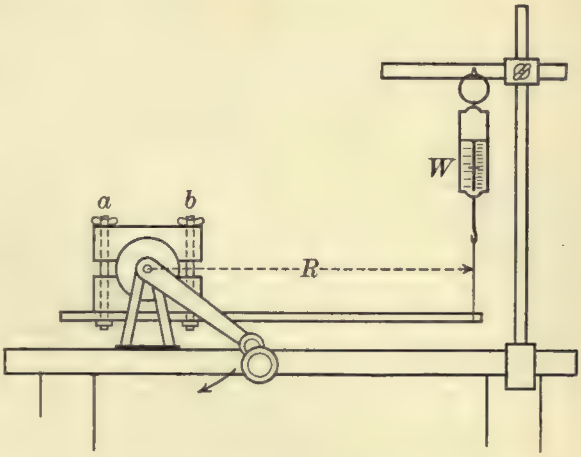
## 33. STUDY OF A PRONY BRAKE

### MUSCULAR EFFORT: HORSE POWER

**Apparatus.** A Prony brake of the simplest order, mounted upon the three-inch pulley of a crank shaft, as in the illustration; spring balance reading to about 16 lb.; support for the spring balance; flywheel to take the place of the crank, in the second part of the exercise, for a study of the dead center and momentum.

The entire apparatus can readily be assembled in the average laboratory from materials already at hand, or it may be purchased ready for use from the apparatus dealers.

A hollow wheel partly filled with water may be used in place of the solid one here shown, to assist in disposing of the heat generated by the friction of the brake if desired.



### EXERCISE

*Object.* (1) To secure acquaintance at first hand with a useful piece of apparatus. (2) To develop through muscular reaction a definite, concrete notion of the meaning of the expression "one horse power." (3) To determine the horse power of an average schoolboy when employed as a machine for turning a crank or a flywheel against a resistance, after the manner of a steam engine.

*Method.* Arrange the apparatus as in the illustration.

Tighten the thumb nuts *a*, *b* until the resistance offered by the brake becomes so great that it will evidently be about all that you can do to keep the crank turning steadily, by the use of one hand, for a period of five minutes. Call another student to keep the time and to read the balance.

Begin the experiment by turning the crank steadily for a period of exactly three minutes, keeping careful count of the number of revolutions and taking care to keep the balance reading as uniform as possible. Record the average reading, $W$, of the balance in pounds, and the number of revolutions, $N$, per minute.

Measure the perpendicular distance, $R$, in feet, from the center of the shaft to the line of direction of the force represented by the balance. Record.

Compute the brake horse power displayed (under the given conditions) by the human machine employed from the formula $\text{B. H. P.} = \frac{2\pi RWN}{33000}$. Record.

Make another trial of two minutes' duration at an increased rate of speed. Apply a small amount of oil to the face of the pulley occasionally, to prevent burning of the brake blocks.

Replace the crank by the flywheel and try again.

Repeat, using the left hand in place of the right.

Answer the following questions: What was the original source of the muscular energy made use of in the experiment? What became of the energy used up? What relation exists between the speed maintained and the horse power required to maintain it? between the resistance to motion and the horse power? What advantage, if any, did you discover in the use of the flywheel? Is it necessary, in determining the brake horse power of an engine, to tighten the brake until the flywheel can barely turn, or is it just as well to apply the brake with less force and allow the engine to run more rapidly? Explain.

*(Form of Record)*

## STUDY OF A PRONY BRAKE

### Muscular Effort: Horse Power

(Sketch)

| *Data* | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Radius $(R) =$ ft. | | | | |
| Revolutions per minute $(N)$ | | | | |
| Balance reading $(W)$ | | | | |
| *Computations and Conclusions* | | | | |
| Brake horse power $\left(\frac{2\pi RWN}{33000}\right)$ | | | | |

Comments

## TOPICS FOR FURTHER STUDY AND INVESTIGATION

Derivation of formula. *Hint:* $2\pi R$, the circumference of the circle of which $R$ is the radius, is the distance through which the load is carried during each revolution of the crank shaft. (This fact will be more clearly seen if the wheel is held fast while the end of the bar to which the balance is attached is moved around the circle, backward, through one complete revolution.) The product of the load and its displacement, $2\pi R \times W$, gives the work done in foot pounds per revolution. (Is this the output or the input? Explain.) Continue the discussion.

Find the horse power of some prime mover (a gasoline engine, an electric motor, or a water motor) in the laboratory by use of a Prony brake.

*Home study.* How large a motor would be needed to run the ice-cream freezer or the clothes wringer used in your own home? *Suggestion:* By means of a spring balance determine the force that must be applied at the handle of the machine to turn the crank under the required load; measure the radius of action; note the number of revolutions per minute required for the most effective work, and compute the indicated horse power. Assume that the motor is 80 per cent efficient and compute the horse power required.

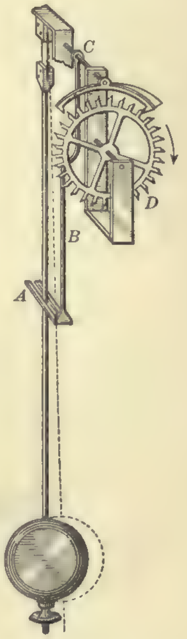
# 34. STUDY OF A CLOCK

## MECHANISM: ACTION

**Apparatus.** A dissected Swiss clock, with the parts mounted on a card and suitably designated by letters or numbers.

### INTRODUCTION

In assembling the parts of a clock, as required in the first part of this exercise, one must remember that he is dealing with a very delicate piece of mechanism. The parts must be handled with great care. Do not attempt to crowd or push anything into place, but work carefully, lest a bent pivot or a twisted wheel spoil everything and prevent the clock from running.



As long ago as 1583 Galileo discovered, by watching the swaying of a chandelier in the cathedral at Pisa, that a simple pendulum, when in motion, always keeps time, that is, makes just so many swings backward and forward each minute, the number depending entirely upon the length of the pendulum.

To understand the action of a clock, then, we must keep our eyes on the pendulum or its equivalent, for the pendulum is the true timekeeper, the rest of the clock serving merely to keep the pendulum going and to count its beats.

The illustration shows the pendulum of a modern clock, with the mechanism that drives it. The escapement wheel *D*, driven in the direction of the arrow by the weight or the spring, pushes against the pendulum, through the escapement lever *B*, and prevents its motion from dying out.

### EXERCISE

*Object.* To see how a clock is put together and to learn how it works.

*Method.* 1. *To assemble the parts* (from directions accompanying the apparatus):

*a. The motor section.* (1) Lay the wooden case frame *A* (see illustration on page 75) down flat upon the table, the legs uppermost and the nickel-plated piece with the two large holes in it next you.

(2) Set the small pivot of the chain wheel *B* into the largest of the three holes seen in the brass strip upon the upper wooden plate.

(3) Pass one end of the weight chain through the hole *O*, around the chain wheel *B*, and back through the hole *P*. Then secure the ring, to be found in the box, to the left end of the chain and the hook, which is to carry the weight, to the right end.

(4) Set the center wheel *C* with its pinion uppermost into the next hole of the upper wooden plate and the escapement wheel *D* into the remaining hole in such a way that the teeth of *B* shall play into the pinion of *C* and the teeth of *C* into the pinion of *D*.

(5) Place the shaft of the escapement lever *E*, which carries also the hook for the pendulum rod, next the escapement wheel *D* by letting it into the cutting of the wooden frame *A* until its pivot fits into the hole provided for it in the lower wooden plate — the long bent wire that is to carry the pendulum rod swinging in between the two wooden plates, while the tiny arms of the lever play into the teeth of the escapement wheel.

(6) Remove the nut *Q* and the washer *N* from the end of the long pivot of the chain wheel *B* and return them to the box for safe-keeping. Place the wooden plate *F* on the frame *A* in such a way that the long pivot of chain wheel *B* comes through the largest hole in the brass slip beneath the plate, while the four holes in the corners fit lightly over the four posts. Next insert the pivots of

the two wheels and the escapement into the respective holes provided for them and gently push the wooden plate down into place, being very careful not to crowd, until each pivot is exactly in the spot intended for it. The motor section is now complete except for the pendulum and the weight.

*b. The dial section:* (1) On the long pivot of the chain wheel put the cannon pinion *L* so that the small wheel of the latter is next the wooden plate *F*.

(2) Place on the pivot near the middle of the plate the minute wheel *K* in such a way that its teeth fit into the cannon pinion *L*. To prevent this minute wheel from coming off, there is provided an arm *S*, made of steel, and this arm must now be so turned that the little ring on the end comes right over the pivot of the minute wheel.

(3) Slip the hour wheel *M* over the cannon pinion *L* so that its teeth may play into the pinion of the minute wheel *K*.

(4) Place the dial on the case in such a way that the long pivot of the chain wheel comes through to the front and the four posts at the corners of the case-frame fit into the holes provided for them. Secure the dial in place by pushing the several hooks *G* through the little holes to be found in the sides of the posts, one in each post.

(5) Place the small hour hand carefully on the hour-wheel tube that you now see sticking up through the dial, and press it gently into place so that it may fit down snugly and leave room for the minute hand above it. Then place the minute hand above the hour hand in such a way that its oblong hole exactly fits upon the square shoulder of the cannon pinion, and press it firmly into place. Now place the small washer *N* over the hands, and finally screw the nut *Q* on top of all, so as to hold everything snugly.

(6) Set the clock by moving each hand separately to its proper place, the minute hand first.

(7) Turn the clock over and put the nickel top *J* in position by gently springing it into place. Then slip the small wooden strips *H 1* and *H 2* into the grooves provided for them at the sides of the case.

It only remains now to hook the pendulum on the escapement lever *E* by reaching up through the opening in the bottom of the case, hang up the clock, hook the weight on the chain, and set the timepiece going by giving the pendulum a slight swing. In hanging the clock take pains to see that it is placed flat against the wall and its position adjusted until the ticktack is regular. The timepiece is wound up by pulling down the chain on the side opposite to the weight. A small bottle of oil will be found in the box for use upon the pivots.

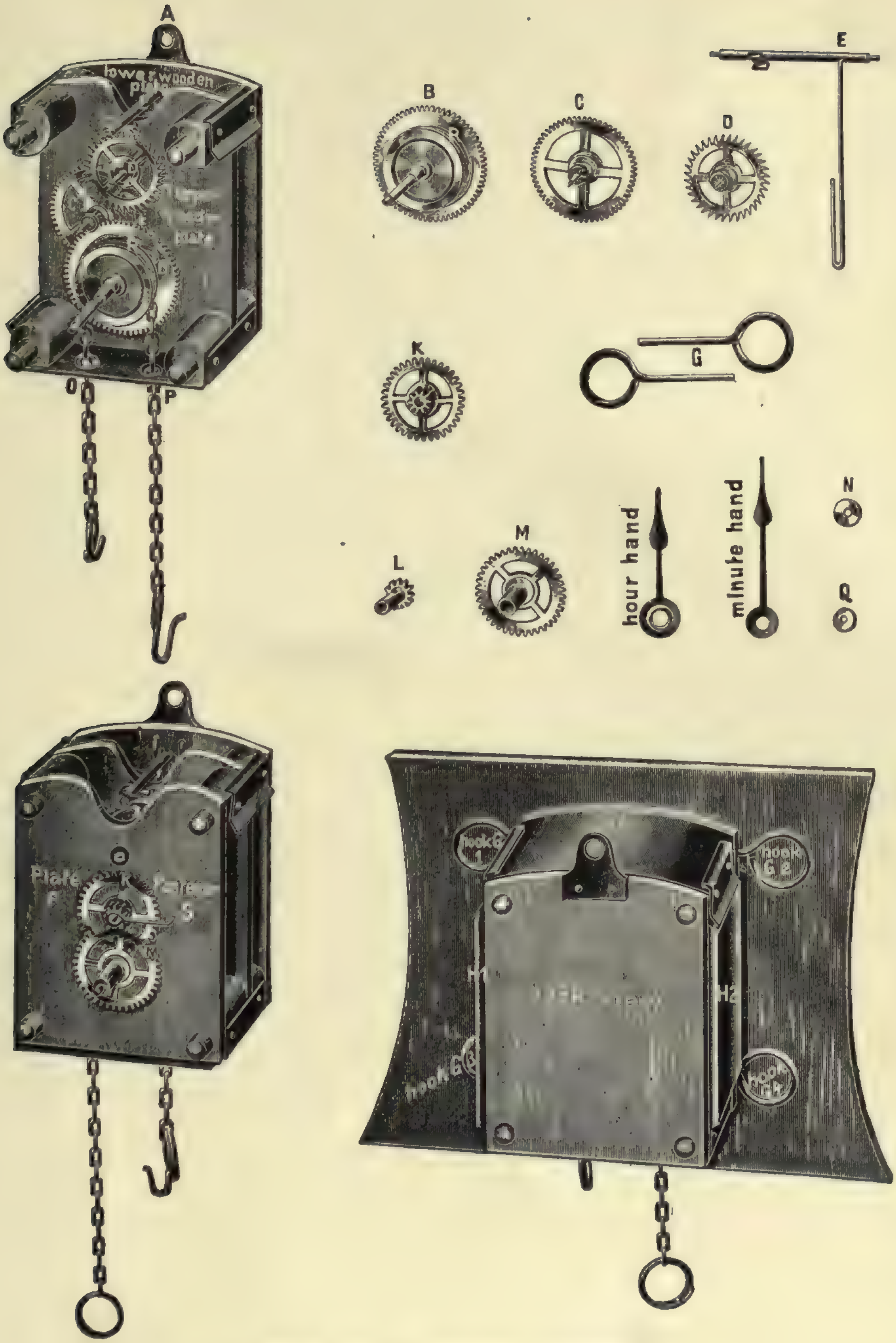
2. *To study the action:*

*a. The pendulum.* By a single oscillation of a pendulum is meant a double swing, once forward and once backward.

With watch in hand, count the number of oscillations per minute. Shorten the pendulum by sliding the bob up the pendulum rod as far as it will conveniently go, and count again. Lengthen the pendulum by moving the bob down to the end of the rod, and count again. Devise a rule for regulating a clock by an adjustment of the pendulum. Restore the bob as nearly to its original position as possible, and count again. Calculate the period of the pendulum; that is, the time represented by a single oscillation. Of what use is the pendulum?

*b. The escapement lever E; the escapement wheel D.* Remove the hands and the dial. Tie a bit of white thread to the rim of the escapement wheel as a marker. Set the clock in motion again. How many teeth of the escapement wheel are allowed to pass (escape) at each oscillation (double vibration) of the pendulum? How many teeth has the escapement wheel? How much time, then, is represented by one revolution of the escapement wheel? What is the use of the escapement lever?

*c. The center wheel C; the chain wheel B.* Remove both; also the escapement wheel. Count the number of pinion wires in the pinion of the escapement wheel and the number of teeth in the rim of the center wheel. How many revolutions of the escapement wheel to one of the center wheel? How much time, then, is represented by one revolution of the center wheel?



Swiss Clock: Details of Mechanism

Count the number of pinion wires in the pinion of the center wheel and the number of teeth in the rim of the chain wheel. How many revolutions of the center wheel to one of the chain wheel? How much time, then, is represented by one revolution of the chain wheel? How much time ought this to represent if the clock is to register correctly and the chain wheel is to carry the minute hand? Error? How is this error to be accounted for? Use of the escapement wheel? of the center wheel? of the chain wheel?

*d. The cannon pinion L; the minute wheel K; the hour wheel M.* Examine carefully. Determine the use of each, and show clearly how it is brought about by the combination that the hour hand moves once around the dial while the minute hand is revolving twelve times.

*e. The weight.* Find its value in pounds. Determine how many feet it falls in twenty-four hours. Calculate the work done per day, of twenty-four hours, in foot pounds, and the rate of working in horse power. (One horse power equals 33,000 ft.-lb. per minute.) Would the rate of the clock be increased or decreased by increasing the weight? Why? Try it and see. What is the use of the weight? Examine the chain wheel. Note the sprocket that carries the chain. Behind the sprocket lies the ratchet. What is its use?

*f. The hands.* From what you have learned of the interior mechanism of the clock would you say that the hands move continuously or at regular intervals? Why can we not see the hour hand move? Through how many degrees does it turn in an hour? Through how many degrees does the minute hand turn in a minute? What is the use of the hands? A moment's reflection will show that the hour hand serves to record the number of complete revolutions made by the central spindle, while the minute hand keeps run of the fraction of a revolution, in sixtieths, left over. Since the rate of the central spindle, a part of the chain wheel in this case, is regulated by the swing of the pendulum, a clock of this order, as stated at the beginning of the exercise, is to be regarded as a machine for keeping run of the oscillations of a pendulum. A clock keeps time because the pendulum does.

Write up the exercise in the form of an illustrated article upon the Mechanism of a Clock, stating the essential parts of the clock and the use of each part.

## TOPICS FOR FURTHER STUDY AND INVESTIGATION

Alarm clock. Remove the case; mount the movement on a block of wood and set it in motion; study each part of the movement separately and explain its action. (*Suggestion:* Interview a local watchmaker or consult an encyclopedia.) The balance wheel is the true timekeeper; the rest of the mechanism serves to keep the balance wheel in motion and to reveal its rate of motion, expressed in hours and minutes, on the dial.

Watches. See *Popular Science Monthly* for May, 1917.

Time: sidereal, mean, standard; noon signals.

# 35. STUDY OF A SEWING MACHINE

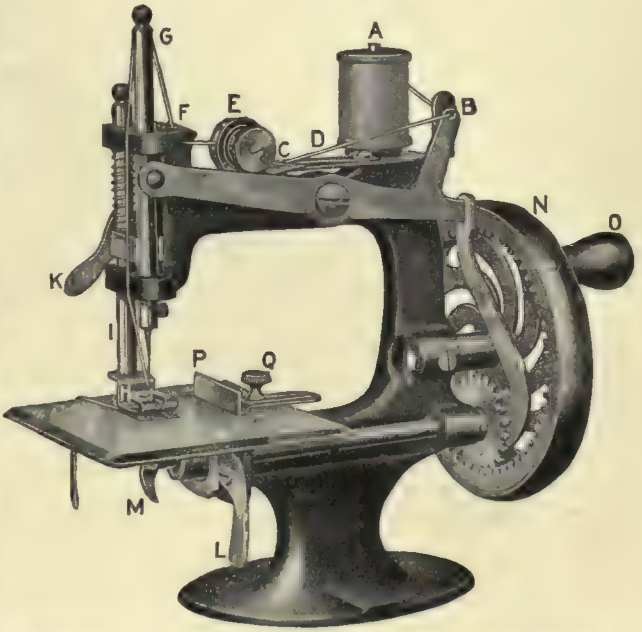
## MECHANISM: ACTION

**Apparatus.** Sewing machine. The illustration shows a small model embodying the fundamental principles of the single-thread chain-stitch sewing machine, intended for practical use and capable of doing some excellent work.

### INTRODUCTION

In considering the action of a sewing machine, one needs to note, first of all, that here the needle enters the cloth at right angles to its surface instead of on a slant, as in sewing by hand. The needle, carrying the thread with it, comes directly back, therefore, after piercing the cloth, by the same hole through which it entered the fabric. There could be no stitch formed at all, then, if the thread were not caught and fastened upon the underside of the cloth by some sort of a looping or shuttle arrangement at each stroke of the needle.

From this it will be seen that the *essential parts* of a sewing machine are as follows: a needle, carrying a thread, with the mechanism required to drive it, and a looping device for making the stitch.



*A*, spool pin; *B*, thread pull-off; *C*, thread hole in nipper lever; *D*, automatic tension (nipper lever); *E*, fixed tension; *F*, thread hole in arm; *G*, thread hole in needle bar; *H*, presser foot; *I*, presser bar; *K*, presser-bar lifter; *L*, stitch regulator; *M*, looper; *N*, balance wheel; *O*, balance-wheel handle; *P*, guide; *Q*, guide screw

The following *accessory parts* may be found: a spool holder, some sort of tension device to keep the thread running smoothly and to assist in drawing up the stitch, a presser foot to hold the work in place, a feed arrangement for pushing the work forward evenly under the needle as the sewing progresses, a stitch regulator for producing a long or a short stitch at pleasure, and, in the larger machines, a few other simple devices that add to the convenience of the operator and to the efficiency of the machine. If the machine is to be driven by foot power, to the above list of parts must be added the following: a treadle, a drivewheel, a pitman (connecting rod), a belt, and a device (found in many of the latest models) to prevent the machine from starting in the wrong direction.

In the model before you, under *essential parts* note the following: the needle, carrying its thread, with the mechanism for driving it (consisting of the needle bar, the lever, the fulcrum, and the connecting rod, in the form of an inverted interrogation point, the large and small gear wheels, the flywheel, and the handle, or crank), and the looping device (to be studied more completely later), in the shape of a hook driven by the small gear wheel through the long shaft at the bottom.

Under *accessory parts* note the following: the spool holder; the automatic tension; the presser foot, held in place by the presser bar and the presser spring until raised by the lifter; the feed arrangement, made up of the feed, the feed spring, and the fulcrum screw; the stitch regulator; and, finally, the clamp for fastening the machine to a table. Locate all of these parts in connection with the actual machine before taking up the more formal part of the exercise.

## EXERCISE

*Object.* To study the mechanism and the action of a sewing machine.

*Method.* 1. *The presser foot.* Raise the presser foot by means of the lifter. Sketch the device called the presser-bar lifter, and show how it accomplishes its purpose. Such a piece of mechanism is known as a lever and cam. What determines the height to which the lever may be lifted by the cam? What is the use of the presser spring?

2. *The feed arrangement.* Raise the presser foot out of the way. Turn the handle slowly and see if you can determine just how the feed works. Sketch the device and explain its action. What is the use of the feed spring?

3. *The stitch regulator.* Raise the needle to its highest point. Lift the presser foot if it is not already up, and insert a strip of paper beneath the needle; then drop the presser foot. With the needle unthreaded, work the machine as if sewing. Note the length of the stitch; that is, the distance between the successive perforations made by the needle. Move the stitch-regulator lever and note the effect upon the length of the stitch. Sketch the entire device — the lever and cam and the feeding arrangement. Explain briefly its action. Write terse, simple directions for lengthening or shortening the stitch.

4. *The looping device.* Make ready for sewing as explained in the sheet of directions accompanying the apparatus. Hold the machine firmly in your left hand in such a way that you can see clearly the motion of the hook, or looper, under the cloth plate. Turn the handle slowly with your right hand. Study the motion of the hook until you see clearly how it operates to loop the stitch. Try your hand at describing its action.

5. *The automatic tension.* Direct your attention to the thread as seen when the machine is held upright. What is the object of running the thread through the top of the needle bar? What happens to the device *D* (see illustration) when the needle reaches its highest point? What is the object of this action? How is it related to the formation of the chain stitch begun by the hook below the cloth plate? Examine first one device and then the other to discover exactly how their combined action, together with that of the needle bar, forms the completed stitch. Sketch the automatic-tension device in connection with the lever which operates it, and describe its action.

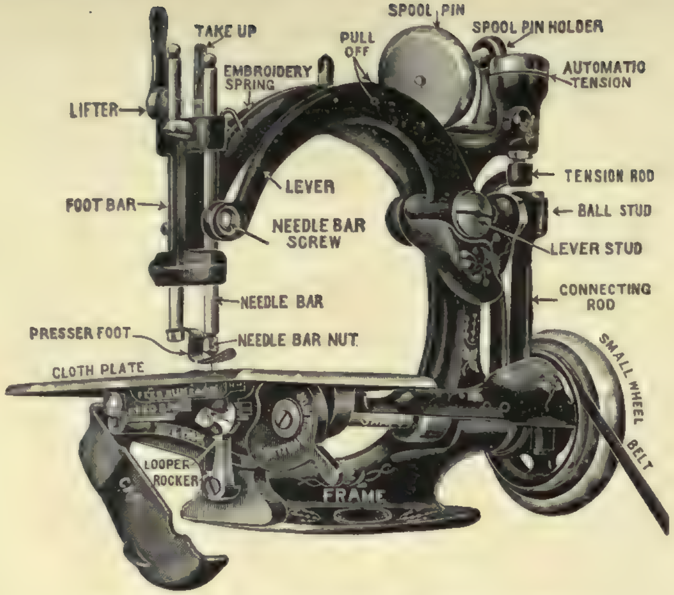
Finally, write an article upon the sewing machine or upon some important feature of the mechanism, describing its action as completely as possible and illustrating by simple sketches.

## TOPICS FOR FURTHER STUDY AND INVESTIGATION

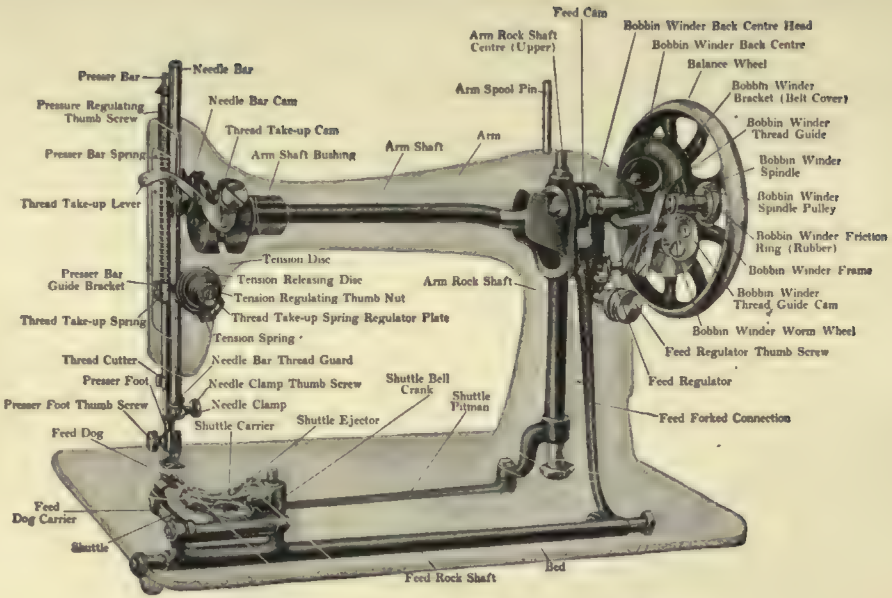
The family sewing machine: single-thread, double-thread — advantages and disadvantages of each type; shuttles — vibrating, oscillating; tension devices; attachments.

Your home machine. Answer as many of the following questions as possible (the information may be gathered from your own observations and experiments, from the book of directions that accompanies the machine, or from the abundant literature that is supplied without cost by the manufacturers): What is the name of the machine? Is it a single-thread (automatic) or a double-thread machine? a rotary-hook, a rotary-shuttle, an oscillating-hook, an oscillating-shuttle, or a vibrating-shuttle machine? By what means is the oscillating motion of the treadle converted into a rotary motion at the drivewheel? Determine the circumference of the drivewheel and the circumference (inside the belt groove) of the balance wheel. Which wheel revolves the faster under the impulse of the treadle? Why? Verify by actual count. Why is the balance wheel made so heavy?

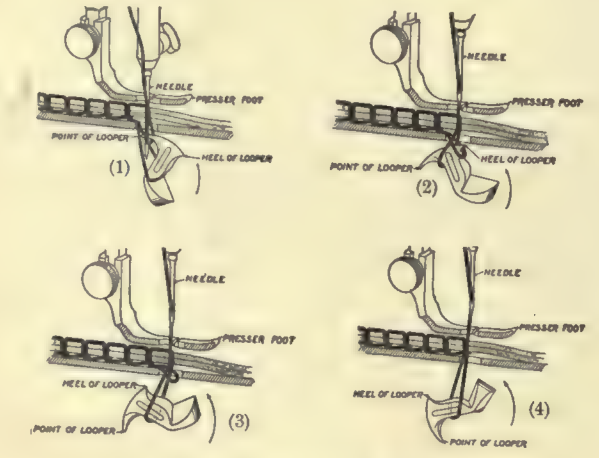
How many stitches per minute does the machine make when sewing rapidly and under the most favorable circumstances? (*Suggestion:* Count the number of stitches made in fifteen seconds, and compute.) How many revolutions of the balance wheel does this number of stitches represent? How many stitches to each complete vibration of the treadle? Between what limits (number of stitches to



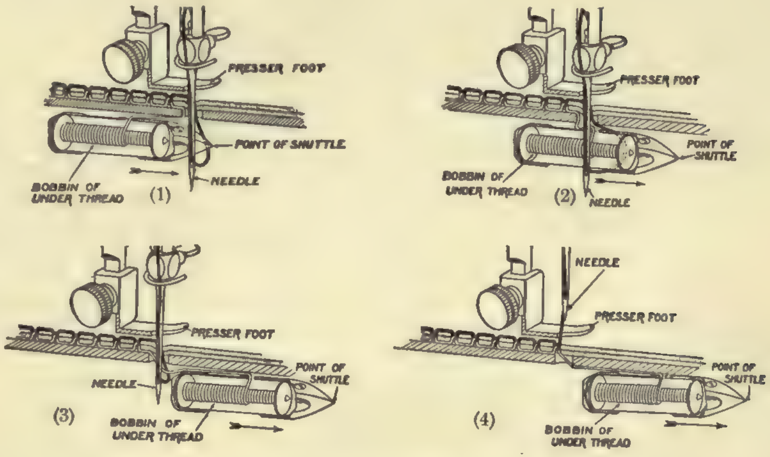
Single Thread; Chain Stitch; Rotary Hook



Double Thread; Lock Stitch; Vibrating Shuttle



Formation of Chain Stitch



Formation of Lock Stitch

Typical Sewing Machines

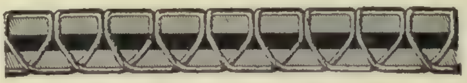
the inch) can the length of the stitch be regulated? How is the stitch fastened, in the single-thread machine, at the end of the seam? Remove the face plate (in front of the needle bar), if the machine has one, and the cloth plate (under the needle); uncover as many other parts as possible and turn the machine slowly by hand. How does the feed arrangement work? How does the stitch regulator operate to lengthen or shorten the stitch?

Restore the machine to its original condition and arrange it in such a way that the under parts are clearly visible. Study the movement of the hook or shuttle with great care, while the machine is stitching slowly, and observe the formation of the knot. How is the rotary motion of the balance wheel converted into a reciprocating (to-and-fro) motion at (1) the needle bar, (2) the take-up lever, (3) the automatic tension, (4) the vibrating shuttle? In the absence of an automatic tension, how does the fixed tension work? What are the rules for its use? What is the use of the take-up lever?

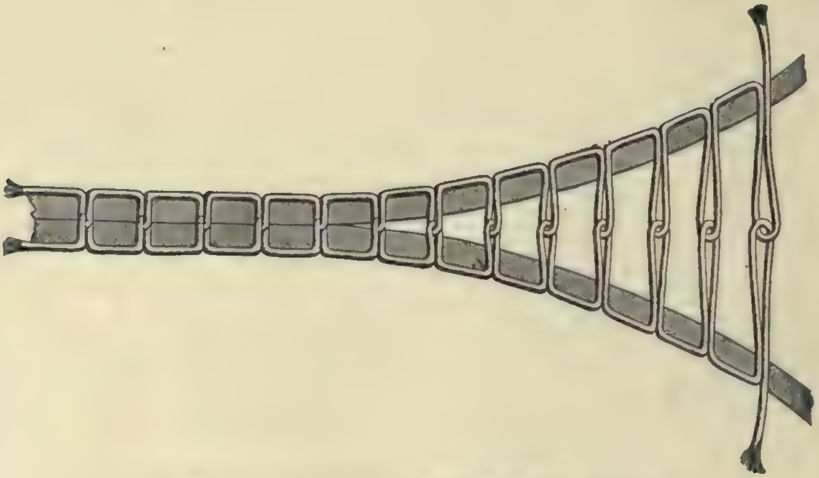
How many illustrations of the six simple machines (see p. 61) are to be found in your sewing machine, and where are they located?

Make a sample seam on the bias: stretch the seam in the direction of the stitching. Is the stitch firm or does it give way? Does the seam ravel easily?

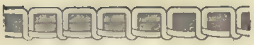
What advantages are claimed for this particular machine by the manufacturers? Are the claims borne out by your own experience?



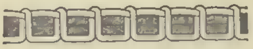
Ordinary Stitching by Hand



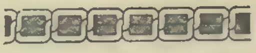
Lock Stitch as made on a Modern Sewing Machine



Loose Upper Tension



Tight Upper Tension



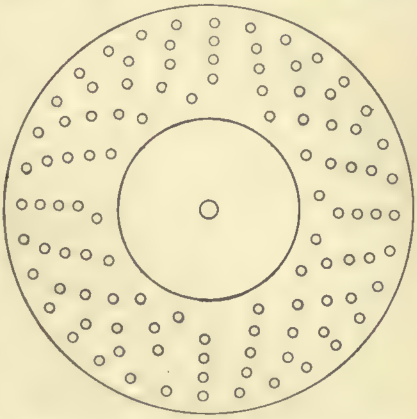
Perfect Stitch

# 36. STUDY OF A MUSICAL SOUND

## MELODY; PITCH

**Apparatus.** A siren disk with five rows of holes; rotator fitted with a revolution counter; blowpipe; pitch pipe or tuning fork; timepiece; xylophone.

### INTRODUCTION



The sensation of sound is occasioned by pulsations (waves) of air that strike against the drum of the ear in much the same way that waves of water strike against a rock on the shore. Musical sounds are caused by pulsations that are evenly spaced; pulsations that are unevenly spaced give rise to noises. The pitch of a musical sound is determined by the rate of vibration of the sounding body, or by the number of sound waves per second that are transmitted to the ear.

Pitch is usually determined indirectly, either by comparing the given sound with a sound of standard pitch or by relating it to some other sound whose pitch can be easily determined. The siren disk is a metal disk perforated by a number of evenly spaced holes grouped in concentric circles about the center of the disk and arranged to be mounted on a rotator for revolution at a considerable speed (either by hand or by an electric motor), after the manner of a flywheel. A blast of air blown against the disk through a small pipe, placed with its open end opposite a row of holes while the disk is rotating rapidly and at a uniform speed, gives rise to a definite musical tone whose pitch clearly depends upon the number of puffs of air (vibrations of the air column) per second that are allowed to pass through the holes in the disk. Since this number can be easily computed by multiplying together the number of holes in the chosen circle and the number of revolutions per second of the disk, we can in this way determine the number of vibrations of any given note emitted by the siren disk, and at the same time, of course, the pitch of any other sounding body that is in unison with it.

### EXERCISE

*Object.* To determine the pitch of a given musical sound by the use of the siren disk.

*Method.* 1. *Preliminary.* Mount the siren disk on the shaft of the rotator and secure it firmly in place. Set the disk to rotating rapidly and blow a blast of air through each row of holes in succession, beginning with the outer row. Note the pleasing effect of the tones emitted by the first four rows; the tones produced by the first and fourth are an octave apart.

Count the number of holes in each of these four rows; the numbers are to each other as 4 : 5 : 6 : 8.

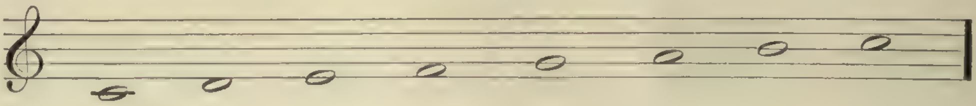
Tones whose vibration frequencies are to each other in the continuous ratio of the simple numbers 4, 5, 6 produce a pleasing effect upon the ear — a simple melody; when sounded together they produce a harmony. Two tones are an octave apart when their vibration numbers are as 1 : 2. The natural scale (do, re, mi, fa, sol, la, si, do; C, D, E, F, G, A, B, C′) is based on these two principles, being founded on the notes of three major triads. Sound the notes CEG, FAC′, GBD′ on the xylophone or on a piano.

How do you account for the effect produced by the fifth row of holes?

2. *Pitch.* Sound a given note on the pitch pipe or by striking a tuning fork on the heel of your shoe. Sound the same note on the siren, taking care to see that your assistant keeps the disk turning uniformly after the tone has once been reached, and determine the number of revolutions per second of the disk. Note the number of holes in the circle made use of, and compute the pitch. Make several trials; select the result that seems to you most likely to be correct, and see if you can locate the note on the scale below. Does the result agree with the number or letter marked on the tuning fork or the pitch pipe? Sound the corresponding note on the xylophone or on the piano.

*Musical scale.*

Notes



| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Names | c′ | d′ | e′ | f′ | g′ | a′ | b′ | c″ |
| Vibration numbers | 256 | 288 | 320 | 341.3 | 384 | 426.6 | 480 | 512 |
| Vibration ratios | C | 9/4C | 5/4C | 4/3C | 3/2C | 5/3C | 15/8C | 2C |
| Intervals | | 9/8 | 10/9 | 16/15 | 9/8 | 10/9 | 9/8 | 16/15 |

The scientist selects middle C (c′) for his standard of pitch and assigns to it 256 vibrations per second; the piano tuner and the violinist select the A above middle C (a′) as their standard of pitch, raise it to 435 vibrations per second, and speak of the result as the *international pitch.*

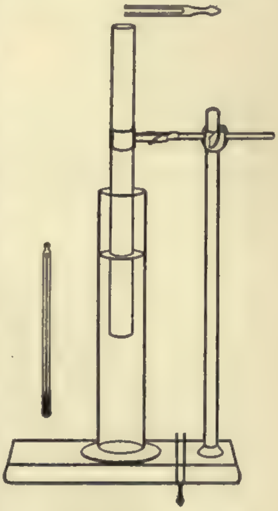
## 37. STUDY OF A TUNING FORK

### WAVE LENGTH: VELOCITY OF SOUND IN AIR

**Apparatus.** Tall glass jar; heavy glass tube 1½ in. in diameter and 18 in. long; two tuning forks of different pitch; centigrade or Fahrenheit thermometer.

#### INTRODUCTION

A vibrating tuning fork, when sounding over an open pipe, as in the illustration, sends an impulse (known as a *condensation*) downward upon the downstroke (a half vibration, counting from the central position) and an impulse upward at each upstroke (a half vibration). The downward impulse travels to the closed end of the pipe, or lower end of the air column, is reflected backward, and, if the air column is of exactly the right length, returns just in time to assist the next upward impulse, and so increases the volume of sound given out by the fork. Under these circumstances, since the condensation has traveled to the bottom of the air column and back during a half vibration of the tuning fork, the distance down and up is equivalent to a half wave length, or the distance one way is equivalent to a quarter wave length, of the note emitted by the fork used. Experiments have shown that to get a true quarter wave length (owing to certain reflections backward and forward across the jar) one must add to the above distance a quantity equal to one fourth the diameter of the tube. The true wave length can then be determined, of course, by multiplying the last result by 4. The wave length, multiplied by the number of vibrations per second (usually marked upon the fork), gives the distance that the sound travels in one second or the velocity of sound in air at the temperature of the air column measured. To determine the velocity at 0° C. one must subtract 1.8 ft. for each degree C., or 1 ft. for each degree F., that the observed temperature is above the freezing point of water (0° C., 32° F.).



Designers of such musical instruments as fifes, cornets, trombones, and organ pipes take advantage of the principle of resonance, illustrated by the behavior of the air column in the above experiment, and shape the hollow parts of their instruments in such a way that the inclosed air columns will in each case reënforce the note to be sounded.

Give other examples of the use of resonant air columns in everyday life.

#### EXERCISE

*Object.* To determine the wave length of a given tuning fork and the velocity of sound in air.

*Method* (preferably for two students working together). Fill the jar partly full of water; adjust the heavy glass tube as in the sketch; sound one of the forks by striking it upon a book, a piece of soft wood, or the heel of your shoe; hold the tuning fork above and as close as practicable to the open end of the tube without actually touching it; and, while the fork is sounding in this position, raise or lower the glass tube until the fork booms out loud and clear. Experiment carefully until you are sure that you have found the position of greatest effect, and then ask the second student to measure in inches, as closely as possible, the distance from the open end of the pipe to the surface of the water inside. Take the temperature of the air column inside the tube above the water. Measure the inside diameter of the tube. Note the vibration frequency of the fork. From these facts compute the wave length of the fork and the velocity of sound in air at 0° C. Repeat, using the second fork. Record as below and compare with the value for sound velocity as kept on file by the instructor.

(*Form of Record*)

## STUDY OF A TUNING FORK

### Wave Length: Velocity of Sound in Air

| | I | II |
|---|---|---|
| *Data* | | |
| Length of resonant column | | |
| Temperature | | |
| Diameter of tube | | |
| Vibration-frequency of fork | | |
| *Computations and Conclusions* | | |
| Quarter wave length | | |
| Wave length | | |
| Velocity of sound at given temperature | | |
| Velocity of sound at 0° C. | | |

### PROBLEMS

**1.** On a day when the temperature is 70° F. an echo is heard from a neighboring cliff two seconds after the sound that gave rise to it is uttered. Compute the distance of the cliff from the observer.

**2.** The sound of a thunder clap is heard 5 sec. after the flash of the lightning is seen. Compute the distance of the cloud from the observer.

**3.** On the assumption that the velocity of sound in air is 1120 ft. per second, compute the wave length of the note G in the octave beginning with middle C of the natural scale (see page 82), and the length of its resonant column.

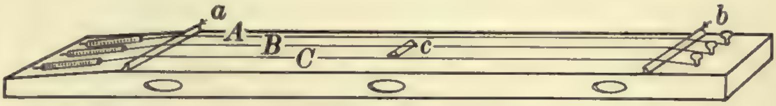
**4.** What must be the length of a stopped (closed at one end) organ pipe that is to sound the B above middle C? In tuning a pipe organ, care is taken to keep the temperature of the organ loft constant and at the same point as when the organ is in use. Why is this?

## 38. STUDY OF A VIBRATING STRING

### PITCH

**Apparatus.** Sonometer with two strings of No. 3 and one of No. 5 pianoforte wire; tuning fork $c^{I}$ (256 vibrations per second).

#### INTRODUCTION



For purposes of classification the stringed instruments of the concert hall may be divided into three groups, according as their strings are picked, bowed, or struck. The representatives of these groups most likely to be found in the home are the mandolin, the violin, and the piano. The mandolin has eight strings, tuned in unison pairs as follows: gg, $d^{I}d^{I}$, $a^{I}a^{I}$, $e^{II}e^{II}$; the range of the instrument is from gg to $e^{III}$. The violin has four strings: three of these are of plain gut and the fourth is of gut wound with fine wire; the strings are tuned to represent g, $d^{I}$, $a^{I}$, $e^{II}$; the range of the instrument is from g to $c^{IV}$. The pianoforte has eighty-eight sets of strings, and these are tuned to cover, by half steps, a range of seven and one third octaves (from $A_{II}$ to $c^{V}$).

#### EXERCISE

*(For the musically inclined)*

*Object.* To determine the effect upon the pitch of a vibrating string of a variation in (1) the length, (2) the diameter, and (3) the tension of the string.

*Method.* 1. *Law of lengths.* Tune each of the smaller wires, $A$ and $B$, to the pitch of the tuning fork $c^{I}$. Record the length of the wire $A$ and the pitch of its fundamental tone (256 vibrations per second) (see *Form of Record*). Place a movable bridge $c$ under the wire $B$ at a point halfway between the fixed bridges $a$ and $b$, and compare the tone given out by either segment, when the string is plucked with the finger, with the tone given out by the wire $A$ when plucked in the same manner. Locate the new note on the musical staff, and from the tabular statement shown on page 82 determine its pitch (number of vibrations per second). Record the length of the string (segment) and the pitch. Place the bridge in succession at such points as to give strings of the following lengths: $2/3A$; $3/4A$; $4/5A$. Determine the pitch of the string in each case, and record, together with the length of the string in centimeters, as before. From a study of the record, determine the law connecting the length of a vibrating string with its rate of vibration when the tension is kept constant. State the law in a single sentence.

Where must the bridge be placed to tune the wire to $a^{I}$? to $b^{I}$? What length of segment corresponds to a pitch of 1024 vibrations per second? How can a violinist play a melody on a single string?

2. *Law of diameters.* Measure the diameter of the wire $A$ and the diameter of the larger wire $C$ with a micrometer caliper, or determine the diameter of each wire from a set of tables. Tune the wire $A$, by means of its adjusting peg, to $c^{I}$; note the tension indicated by the reading of the spring balance and bring the wire $C$ to the same tension. Adjust the movable bridge under the wire $C$ until the longer segment of the wire is in unison with the wire $A$; from the law of lengths compute the number of vibrations per second corresponding to the entire length of the wire $C$, and

record. Record the diameter of each wire. From a study of the record determine the law connecting the diameter of the string with its rate of vibration per second when the length and the tension are kept constant.

3. *Law of tensions.* Tune the wire *A* to c$^{\mathrm{I}}$; tune the wire *B* to some other convenient tone; record the square root of the tension in each case and the number of vibrations per second. Make several trials. From a study of the record determine the law connecting the square root of the tension of a string with the number of vibrations per second when the length is kept constant.

(*Form of Record*)

### STUDY OF A VIBRATING STRING

#### PITCH

| | TRIALS | | |
|---|---|---|---|
| 1. Law of lengths | 1. | 2. | 3. |
| Length | | | |
| Pitch | | | |
| Law | | | |

| | TRIALS | | |
|---|---|---|---|
| 2. Law of diameters | 1. | 2. | 3. |
| Diameter | | | |
| Pitch | | | |
| Law | | | |

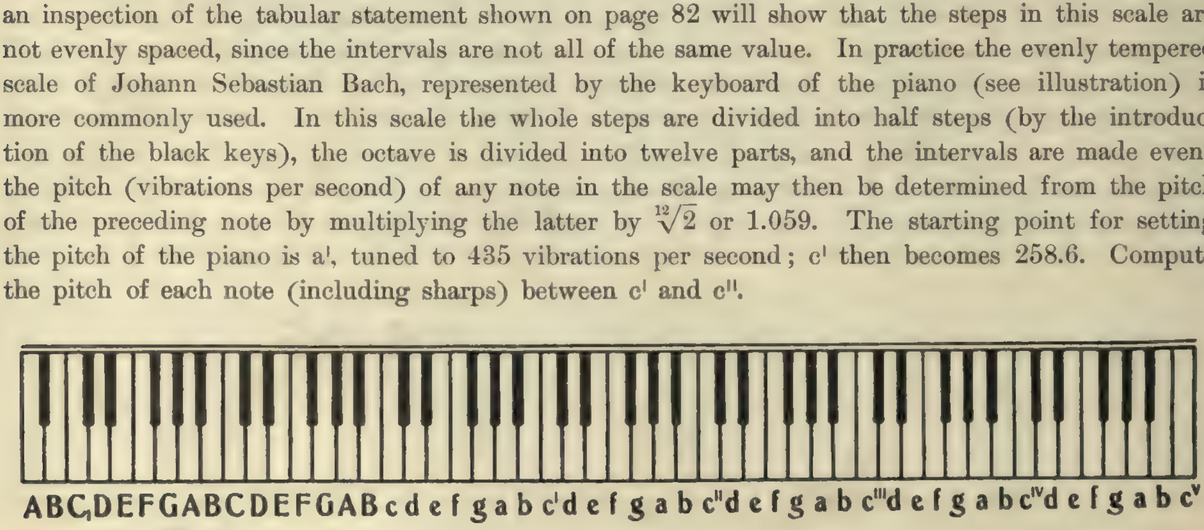
| | TRIALS | | |
|---|---|---|---|
| 3. Law of tensions | 1. | 2. | 3. |
| $\sqrt{\text{Tension}}$ | | | |
| Pitch | | | |
| Law | | | |

### TOPICS FOR FURTHER STUDY AND INVESTIGATION

The principal stringed instruments of the orchestra are the following: violin, viola, violoncello, bass viol, and harp. Look up the characteristics of each instrument.

Examine the interior of a grand piano and report on the characteristics of the strings, the action of the keys in relation to the damping mechanism, and the action of the pedals.

The musical scale thus far referred to is known as the natural scale or scale of just intonation; an inspection of the tabular statement shown on page 82 will show that the steps in this scale are not evenly spaced, since the intervals are not all of the same value. In practice the evenly tempered scale of Johann Sebastian Bach, represented by the keyboard of the piano (see illustration) is more commonly used. In this scale the whole steps are divided into half steps (by the introduction of the black keys), the octave is divided into twelve parts, and the intervals are made even; the pitch (vibrations per second) of any note in the scale may then be determined from the pitch of the preceding note by multiplying the latter by $\sqrt[12]{2}$ or 1.059. The starting point for setting the pitch of the piano is a$^{\mathrm{I}}$, tuned to 435 vibrations per second; c$^{\mathrm{I}}$ then becomes 258.6. Compute the pitch of each note (including sharps) between c$^{\mathrm{I}}$ and c$^{\mathrm{II}}$.


ABC₁DEFGABCDEFGABcdefgabc$^{\mathrm{I}}$defgabc$^{\mathrm{II}}$defgabc$^{\mathrm{III}}$defgabc$^{\mathrm{IV}}$defgabc$^{\mathrm{V}}$

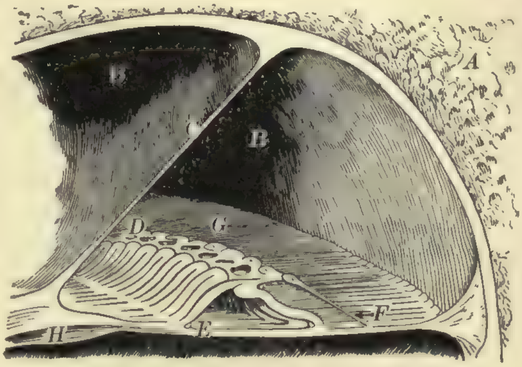
## 39. STUDY OF THE HUMAN EAR

### DEFECTS OF HEARING: TEST

**Apparatus.** An *ear test* (a device, in the form of an electric hammer actuated by a solenoid or an electromagnet, for the production of a fixed and definite sound in response to the push of an electric button); or a ticking watch.

### INTRODUCTION

The human ear is a wonderful instrument; provided in its innermost recesses with a *harp of three thousand strings*, it is capable of responding to as many variations of tone entering from the outside world, and it has been known to report to the brain, through the auditory nerve, minute gradations of sound covering the entire scale (over a range of eleven octaves) — from sixteen vibrations a second to over thirty thousand. The limits of audibility, at the upper end especially, vary greatly among different individuals: some people are able to hear such shrill sounds as the cry of a bat or the chirp of a cricket, while others are completely deaf to such high notes. The lower limit can be determined for each person by means of a properly loaded tuning fork, and the upper limit by the use of a graduated pipe, known as Galton's whistle; but as the results are comparatively unimportant, we shall confine our attention to a test for the acuteness of hearing.



*A*, petrous bone; *B*, *B*, interior of spiral filled with fluid; *C*, dividing membrane; *D*, platform of hair cells; *E*, arch of jointed rods supporting the hair cells; *F*, hair of hair cell; *G*, membrane of thousands of strings like the wires of a piano; *H*, nerve

### EXERCISE

*Object.* To test the acuteness of the hearing.

*Method 1. The whispered word* (adapted from the statutes of Massachusetts as amended in 1910). The teacher should conduct the examination in a room not less than 25 or 30 ft. long and situated in as quiet a place as possible. Definite standards must first be obtained by testing persons of normal hearing at known distances. In a still room the standard whisper should be audible to the normal ear at a distance of 25 ft., the whisper of a low voice at from 35 to 45 ft., and the whisper of a loud voice at from 45 to 60 ft. By practice the examiner can standardize his whisper quite accurately. The test words may consist of numbers 1 to 100, and of short sentences.

Place the student at the required distance from you and conduct the examination with the whispered or spoken voice, making use of the standards agreed upon. Ask the student to repeat what he hears and to note the distance at which he hears the words distinctly. Test the two ears separately. To secure the best results, only one pupil at a time should be allowed in the room.

*Method 2. The ear test.* Directions for use. Two pupils should work together, in a quiet room if possible. The instrument is to be hung upon an inner wall of the room, at the height of one's head, and connected with the press button and the dry cell after the manner of an electric bell. The pupil whose hearing is to be tested must be placed directly in front of the instrument and 30 ft. away from it, while the second pupil adjusts the instrument and makes ready to press the button. The examiner first adjusts the instrument for a very light sound by turning the graduated wheel to the point marked 10. He then takes the push button in his right hand and, when the other pupil is in place, with his right ear 30 ft. from the instrument and his left ear stopped with a light wad of cotton, gives a signal, which he repeats at regular intervals, instructing the other to say *now* at each recurrence of the sound. If the pupil's responses come at precisely the right intervals, as indicated by the succession of button pushes, his hearing may be set down as *excellent.* If the responses are not timed correctly, or if the pupil states that he cannot hear the sound, set the dial at 20, for a medium sound, and try again. If he hears correctly this time, his hearing may be regarded as *normal.* If still unsuccessful, set the dial at 30, for a loud sound, and repeat. If he can just hear the sound now, his hearing is *below normal.* If he cannot hear it, his hearing is *deficient* and the case should be reported at once.

The instrument should be tested occasionally by trial with persons whose hearing is known to be normal, to allow for variation in temperature, acoustical surroundings etc., and the position numbers determined anew.

In case the ear-test apparatus is not available, determine the distance from each ear at which the ticking of the watch can be plainly heard, and compare with the distance from the normal ear.

Test each ear separately and report.

(*Form of Record*)

## STUDY OF THE HUMAN EAR

### ACUTENESS OF HEARING: TEST

Name of pupil examined.................................................................... Date..........................................

1. Standard whisper

    Right ear: Distance.......................................................... ft.
    Left ear: Distance............................................................ ft.

2. Ear-test apparatus

    Right ear ..................................................................
    Left ear.....................................................................

*Conclusions*

## TOPICS FOR FURTHER STUDY AND INVESTIGATION

The musical ear. A person who is able to determine the relative pitch of a given musical tone after listening to a standard tone is said to possess a musical ear. How much of this ability is acquired as a result of education and how much of it is inborn is a question that cannot be answered easily; opinions differ widely. Ask a fellow student to set the chromatic pitch pipe at middle *C* and to sound the note for you by blowing steadily into the pipe. Let him then set the index at various other points and sound the corresponding tones while you name them. By comparison with the letter shown opposite the index in each case, determine your percentage of correct answers; or make the test with a piano. How small a musical interval can you detect?

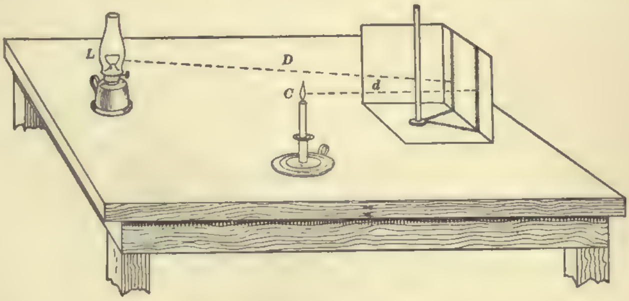
## 40. STUDY OF A KEROSENE LAMP

### PHOTOMETRY

**Apparatus.** Kerosene lamp; Rumford photometer; standard candle; platform balance; metric weights; meter stick.

### INTRODUCTION

One can usually tell by a simple inspection which of two lights, if either, is brighter than the other; but to say how much brighter one is, is not so easy. It is evident that a Welsbach burner gives more light than a tallow candle, but whether it gives 50, 60, 75, or 100 times as much light is a matter that can be determined only by experiment. One of the simplest devices for measuring the relative intensity of two sources of illumination is the Rumford photometer, shown in the illustration. The apparatus consists of an upright rod placed in front of a white screen. The two lights to be compared — the flame of a kerosene lamp and that of a standard candle, for instance — are placed in such a position that the respective shadows of the rod, falling on the white screen in a darkened room, lie side by side; one of the lights is then moved toward the screen or away from it until the shadows are of equal intensity, that is, of the same shade. Experiments have shown that under these conditions the intensities of the two lights are to each other as the squares of their distances from the shadows which they illuminate. Then $L : C = D^2 : d^2$ (see illustration), or $L = \frac{D^2}{d^2} C$. The standard employed may be a standard candle (a sperm candle $\frac{7}{8}$ in. in diameter, burning at the rate of .129 g. per minute — the unit of measure) or an incandescent electric light of known candle power.



### EXERCISE

*Object.* To determine the cost per candle-power hour of a given kerosene lamp when burning brightly.

*Method.* Weigh the lamp and its contents; weigh the candle; light each; note the exact time.

By means of the photometer, determine how many times as bright as the candle the lamp is. Blow out the candle; note the exact time. Weigh the candle again. From the number of grams of spermaceti consumed per minute compute the candle power represented by the standard candle during the experiment (.129 g. = 1 candle power). Compute the candle power of the lamp.

Weigh the lamp and its contents again (it should have been burning at least half an hour). Compute the number of grams of kerosene consumed by the lamp, and the cost per hour at the market price for kerosene (10 cents per gallon = 3.3 cents per kilogram). Compute the cost per candle-power hour.

Illustrate your report by a full-sized drawing of the upper part of the lamp, showing the burner, the chimney, and the flame. Comment on the general appearance of the apparatus and state several conditions that seriously affect the candle power of the average household lamp.

If preferred, a paraffin candle of the size known as "sixes" may be used in place of the sperm candle; it may be assumed without a large error that such a candle, when burning with a flame about 2.5 cm. in length, gives an intensity of illumination of 1 candle power.

The foot candle. The intensity of illumination produced by the light of a standard candle falling on a surface a foot away and at right angles to the light rays is called a *foot candle.* It is the unit of measure for intensity of illumination. A 16-candle-power electric light at a distance of 1 ft. gives an illumination of 16 foot candles. Since the intensity of light diminishes with the square of the distance from the source, the same 16-candle-power light, placed 2 ft. away, gives an illumination of 4 foot candles $\left(\frac{16}{2^2}\right)$; 8 ft. away, $\frac{1}{4}$ foot candle, etc.

What is the intensity of illumination upon a surface 8 ft. from a 100-candle-power lamp? How big a lamp must be employed to produce an illumination of 4 foot candles upon a surface 10 ft. away?

By means of a homemade photometer and a small lamp (kerosene or electric), the candle power of which has been determined in the laboratory, measure the intensity of illumination produced upon the page of your book by the light in your study at home; from 2 to 3 foot candles is ideal; too much illumination leads to eyestrain.

Report on as many kinds of kerosene lamps as you can discover, and discuss the relative merits of each kind.

Ventilation. One quart of kerosene, when burned in a suitable lamp or in a small stove, requires for complete combustion 78.6 cu. ft. of oxygen or 378 cu. ft. of air. The principal products of the combustion are carbon dioxide (55.6 cu. ft.) and water vapor (2.8 lb.). One pound of water vapor saturates 5300 cu. ft. of air at 68° F.

How do you account for the sudden appearance of a film of water vapor on the inside of the cold glass chimney when a kerosene lamp is lighted in the winter? Why is the frost on the windowpane so much more abundant in a room that is lighted by kerosene than in a room that is lighted by electricity? Why does the air in a room that is lighted by a kerosene lamp often seem so close and oppressive to a person entering from out of doors?

A 50-candle-power lamp burns $\frac{1}{2}$ pint of kerosene in three hours. How many cubic feet of air per hour are required to support the combustion? What weight of water vapor is produced? How many cubic feet of air, at a relative humidity of 50 per cent and a temperature of 68° F., could this amount of air saturate? How does the cost per candle-power hour compare with the cost of the illumination furnished by the best lamp in the laboratory or in your own home?

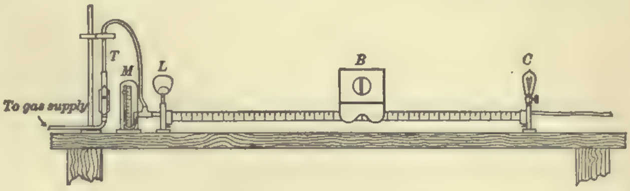
## 41. STUDY OF A GAS JET

### PHOTOMETRY

**Apparatus.** A Thorp gauge or the gas meter used in Exercise 23; Bunsen (or Joly) photometer; Welsbach burner; open-flame burners of various forms and sizes; U-tube manometer; standard candle or electric light of known candle power.

### INTRODUCTION

The light-giving power of an illuminating gas depends on the quality of the gas and the construction of the burner. *Coal gas* is made from bituminous coal by a process of intensive heating carried on in fire-clay retorts heated, without access of air, to a temperature of 1600° F. The by-products of the manufacture are coke, ammonia, and coal tar. From the coal tar are obtained many valuable compounds. Among these are naphtha, carbolic acid, various heavy oils, benzene, and naphthalene. *Water gas* is made by passing steam over white-hot anthracite coal or coke; it is enriched by the addition of oil gas. On account of its high percentage of carbon monoxide (the "coal gas" of the furnace), water gas is highly poisonous, but its escape into the room is easily detected by its characteristic odor. *Acetylene gas* is produced by combining calcium carbide and water. Mixtures of acetylene gas and air are very explosive. An open flame should therefore never be used about an acetylene generator. *Prest-O-lite* is acetylene dissolved in acetone (a by-product from the manufacture of wood alcohol).



The light from an open burner is due to the carbon particles in the flame, which turn white hot before they are completely burned, or united with the oxygen of the air to form carbon dioxide; when air is admitted to the interior of the flame in sufficient quantities to completely oxidize the carbon before it has time to become incandescent, the flame changes from a bright yellow to a delicate blue color, loses nearly all of its light-giving power, and becomes intensely hot; an undersupply of air causes the flame to "smoke," or deposit a portion of its supply of carbon without oxidation.

Burners are constructed to accomplish any one of the above results as desired. The Bunsen burner is designed for heating purposes and is furnished with a liberal supply of air through a series of holes at the bottom of the tube. The Welsbach burner derives its great illuminating power from a delicate mantle composed of the oxides of the rare metals thorium and cerium, which glows with a brilliant white light when heated to incandescence in the flame of a Bunsen burner.

The "lava tips" sold with the ordinary batswing burner are made of clay and are marked with a series of grooves around the shank to indicate, approximately, the amount of gas consumed per hour by each burner under normal conditions. A deep groove marks a two-foot burner, and a shallow groove a one-foot burner; other sizes are denoted by suitable combinations of the two kinds of grooves.

The wire screen, placed inside the tube of the Welsbach burner, is intended to prevent the lighted gas from striking back and igniting at the inner orifice.

The Bray burner has a pressure-reducing device inside the burner; the gas is burned under a low pressure (at the tip of the burner) and produces a steady flame of high illuminating power.

The Massachusetts law requires that illuminating gas shall be of such a quality as to give an illuminating power, when burned at the rate of 5 cu. ft. an hour ("in the burner best adapted to it and at the same time suitable for domestic use"), of 16 standard English candles (burning spermaceti at the rate of 120 grains, or 8.7 g., per hour).

## EXERCISE

*Object.* To determine the relative candle power of various gas jets produced by different styles and sizes of gas burners, and the cost per candle-power hour at the local price for gas.

*Method.* Arrange the apparatus as in the illustration, placing the standard light at *C*, the light to be examined at *L*, the Thorp gauge or the gas meter at *T*, and the manometer at *M*.

Move the photometer box along the bar until the two sides of the screen (or the two blocks of paraffin) appear to be equally illuminated; measure the distances *LB* and *CB*, or read the distances on the scale below, and compute the candle power of the gas jet from the law of the photometer, $L : C = \overline{LB}^2 : \overline{CB}^2$.

The Thorp gauge, by the position of its index against the right-hand scale, indicates the number of cubic feet of gas consumed per hour.

Read the gauge or the gas meter (see Exercise 23) and compute the cost per hour. Compute the cost per candle-power hour. Compute the cost per month (120 hr.). Record the name of the burner used and the average gas pressure (in inches of water) maintained during the test.

Test each of the burners in turn.

Comment on the efficiency of the various burners and the accuracy of their rating as given by the salesman or as marked on the tube.

Experiment to determine the amount of gas consumed, during a period of twelve hours, when the gas is left burning but turned low.

Compare the cost per month (120 hr.) of maintaining a Welsbach light with the cost of furnishing an equal intensity of illumination for the same period of time by the use of a number of open flame burners. *Suggestion:* Include the cost of renewing the mantle.

Make up your own *Form of Record* in tabular form, and report.

*Optional.* Determine the cost per hour of lighting a given room at home as follows: Note the time required for the small hand at the top of the dial on your gas meter to make one revolution (2 cu. ft.) while the gas in the room is burning as usual, with all other jets shut off; make the required computations.

Study the parts of an inverted Welsbach burner and report on the adjustment and use of the controlling mechanism at the top of the burner.

## TOPICS FOR FURTHER STUDY AND INVESTIGATION

Ventilation. One cubic foot of city gas (enriched water gas) requires for complete combustion 1.9 cu. ft. of oxygen or 9.2 cu. ft. of air; the principal products of the combustion are carbon dioxide (.57 cu. ft.) and water vapor (.14 lb.). A given 82 candle-power Welsbach lamp burns 4 cu. ft. of city gas per hour. How many cubic feet of air per hour are required to support the combustion? How does the cost per candle-power hour compare with the cost of the illumination furnished by the Welsbach lamp tested in the laboratory or by the kerosene lamp used in Exercise 40?

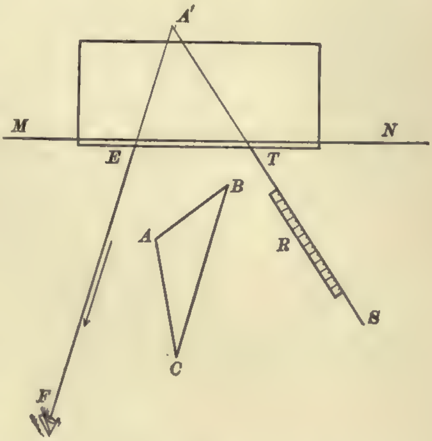
# 42. STUDY OF A PLANE MIRROR

## IMAGES; LAW OF REFLECTION

**Apparatus.** A plane mirror (about 2 in. × 3 in.) secured to a rectangular block by a rubber band; pin; ruler or straightedge; sheet of paper.

### INTRODUCTION

Look into the mirror and observe your own image. Does it appear to be on the mirror, behind the mirror, or in front of the mirror? Move your pencil slowly up to the mirror and as slowly back again; observe the image of the pencil and try to locate its position with reference to the reflecting surface of the mirror. Hold a page of printed matter in front of the mirror and observe the reflection in the mirror; explain. To determine precisely what is here only guessed at is the purpose of this exercise.



### EXERCISE

*Object.* 1. To determine the position and the character of the image formed by a plane mirror.

2. To illustrate the law of reflection of light.

*Method.* 1. With a sharp pencil draw a fine line *MN* (see illustration) across the center of the paper; set the mirror upright on the table, with the back edge of the mirror (the reflecting surface) exactly on this line. Draw a triangle *ABC* on the paper in front of the mirror and observe the image of the triangle in the mirror. Stick the pin upright into the table at the point *A*; lay the ruler *R*, or the straightedge, on the table to the right of *A* and, with one eye, sight along the edge of the ruler toward the image of the pin as seen in the mirror.

Draw a straight line *ST* toward this image, that is, in such a way that, if extended, it would exactly hit the image. Move the ruler to the left of the pin and draw a second line *FE* toward the same image. Remove the ruler. Sight along each line and see if it really points to the image; if not, erase the line at fault and try again. Locate the image point by removing the mirror and prolonging the two lines until they intersect. Letter the point of intersection *A′*. Replace the mirror; set the pin at *B* and *C* in turn; draw the corresponding lines and locate the image point in each case; letter the points *B′* and *C′* respectively. Join the image points by straight lines to form a triangle. Is the image triangle a duplicate of the original as seen in the mirror? If not, erase the image triangle and try again.

Is the image in front of the mirror or behind the mirror? Does the image lie in the same direction as the object, or is it reversed? Is the image larger or smaller than the object? Is the image real (such that it could be made to fall on a screen placed behind the mirror), or is it virtual (imaginary)? Is the image fixed, or does it move as the eye moves? How does the distance from the object to the mirror (object distance) compare with the distance from the image to the mirror (image distance)?

2. Place an arrow beside the line *EF* to show the direction of one ray of light (train of light waves) passing between the mirror and the eye. Did this ray of light come from *A* or from *A′*? Draw *AE*; place an arrow beside this line to show the direction of the ray of light passing from the pin to the mirror. *AE* is called the *incident ray* and *EF* the *reflected ray.* Draw a perpendicular to the surface of the mirror at *E*, between the lines *EA* and *EF*, and letter it *ET*. Compare the angle *AET* (angle of incidence) with the angle *FET* (angle of reflection). State your conclusion. Make a similar construction at various other points on the figure. Is your conclusion borne out in each case?

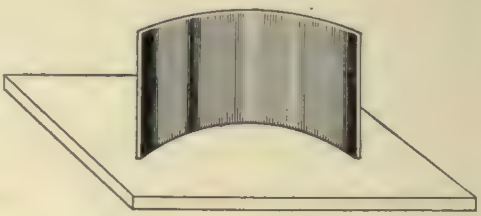
## 43. STUDY OF A CURVED MIRROR

### CONVEX AND CONCAVE MIRRORS: IMAGES

**Apparatus.** A spherical mirror, convex on one side and concave on the other; a cylindrical mirror, of the same construction as the spherical mirror.

### INTRODUCTION

A complete study of the images formed in a curved mirror can best be made through a series of experiments on the lecture table, but a simple qualitative study of the images produced by a small mirror, in the hands of the individual pupil, cannot fail to be instructive.



Parallel rays of light, falling on the surface of a concave mirror, are converged to a point called the *principal focus* of the mirror. The distance from the principal focus to the surface of the mirror is called the *focal length* of the mirror; this distance is practically equal to one half the *radius of curvature* of the mirror. Rays of light coming from a point 100 ft. or more away are practically parallel.

The illustration shows a concave cylindrical mirror, standing on a table, with its straight edges vertical.

### EXERCISE

*Object.* To observe the images formed in a curved mirror.

*Method.* 1. *The convex mirror.* (*a*) *Spherical.* Hold the mirror in front of you, about 12 in. distant from the eye, and observe the image of your own face. Is the image upright or inverted? Is the image larger or smaller than the object?

Hold the mirror at arm's length and observe the length of the image; move the mirror toward the eye and again observe the length of the image. What is the apparent relation between the object-distance (distance from the object to the mirror) and the length of the image? How does the field of view (extent of the object visible at one time) compare with the field of view of a plane mirror having the same superficial area? Of what use is a convex spherical mirror?

(*b*) *Cylindrical.* Hold the mirror in such a position that its straight edges are vertical while the convex side faces you. Describe the observed image. Explain. Turn the mirror until its straight edges are horizontal and again describe the observed image. Explain. Of what use is a convex cylindrical mirror?

2. *The concave mirror.* (*a*) *Spherical.* Hold the mirror in the sunlight, facing the sun, and focus the image of the sun (that is, make the image as small as possible) on a small piece of paper held in front of the mirror; ask another pupil to measure the distance from the image to the mirror; record this distance as the focal length of the mirror; compute the radius of curvature of the mirror.

Hold the mirror at arm's length and move it about until you can see clearly the image of your own face. Is the image upright or inverted? Is the image larger or smaller than the object? Is the image in front of the mirror or behind it? (Consult the instructor at this point.) Is the object-distance greater or less than the radius of curvature? Hold the mirror close to one eye. Is the image upright or inverted? Is the image larger or smaller than the object? Is the image in front of the mirror or behind it? Is the object-distance greater or less than the focal length? Of what practical use is a concave spherical mirror?

(*b*) *Cylindrical.* Hold the mirror in such a position that the straight edges are vertical while the concave side of the mirror faces you. Describe the observed image of your own face. Explain. Turn the mirror into such a position that the straight edges are horizontal, and again describe the observed image. Explain. Of what use is a concave cylindrical mirror?

Write up the exercise in the form of a brief narrative of your experiments, your observations, and your conclusions.

### PROBLEMS

**1.** Why does the image of one's face appear abnormally thin when seen in certain looking-glasses, of a cheap order, while in others it appears abnormally broad?

**2.** Is the front of the glass the real reflecting surface of a looking-glass, or is it the mercury amalgam behind the glass?

**3.** Black mirrors are sometimes made by painting a pane of glass on one side with lampblack. Explain the action of such a mirror.

**4.** What are plate-glass mirrors? Why are they expensive?

**5.** Why are concave mirrors usually more expensive than plane mirrors or convex mirrors?

**6.** Why are shaving mirrors made concave, and why are automobile mirrors made convex?

### TOPICS FOR FURTHER STUDY AND INVESTIGATION

**Reflectors:** spherical and parabolic.

Mount a concave mirror behind a battery lamp and observe the effect upon the reflected rays as the lamp is placed at the following points: (1) at the focus of the mirror; (2) between the focus and the mirror; (3) between the focus and the center of curvature.

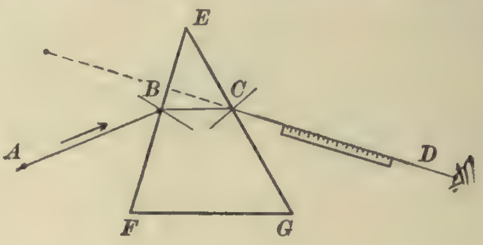
## 44. STUDY OF A RAY OF LIGHT

### REFRACTION: COLOR

**Apparatus.** A glass prism; pins; strips of colored paper; sheet of red glass (3 in. × 4 in.); sheet of blue glass (3 in. × 4 in.).

### INTRODUCTION

Light, in the form of a wave motion, travels through empty space in straight lines at the astounding velocity of 186,000 miles per second. Light-waves within the limits of visibility vary in length from .000015 in. to .000030 in. The shortest of these light-waves, when received by the human eye, creates the sensation of violet; the longest creates the sensation of red. White light is made up of an assemblage of light-waves that vary so greatly in length as to represent all the colors of the rainbow. The three primary colors are red, green, and violet; the combination, in certain proportions, of these colors, when received by the human eye, creates the sensation of white light. The color of an opaque object is due to the fact that the given object absorbs certain colors inherent in the white light falling upon it, and reflects the rest to the eye; similarly, the color of a transparent object is dependent upon the fact that the given object absorbs certain colors inherent in the white light passing through it, and transmits the rest to the eye. The color of the object is determined, in each case, by the color of the light that the object is able to send to the eye. Why does a red rose appear red when viewed under a white light, and why does the same rose appear black when viewed under a blue light? Why do certain colors appear different when seen by gaslight than when seen by daylight?



Any two colors that together produce the sensation of white light are called complementary colors.

### EXERCISE

*Object.* To determine the effect of placing a prism in the path of a ray of light and to illustrate the absorption and transmission of color.

*Method.* 1. Stick two pins upright into the table through a sheet of paper, and draw a straight line *AB* (see illustration) on the paper from one pin to the other, to represent a ray of light passing between the two pins; indicate the direction of the ray of light by an arrow. Place the prism in such a position on the paper that one edge of the prism makes an angle of 45° with the ray of light, and outline the prism with the point of a sharp pencil. Bring one edge of the ruler, lying on the table, into line with the two pins as they appear when seen through the side *EG* of the prism, and draw the line *CD* to represent the path of the ray of light from the prism to the eye. Remove the prism; draw the line *BC* to show the path of the ray through the prism, and draw perpendiculars to the sides of the prism at the points *B* and *C* respectively. Mount the diagram in your notebook.

Did the ray of light as it *entered* the prism bend toward the perpendicular to the surface of the glass or away from it? Did the ray of light as it *left* the prism bend toward the perpendicular or away from it? Is a ray of light passing through a prism bent toward the base of the prism or toward the apex of the prism?

2. Allow a ray of sunlight to fall obliquely upon one side of the prism, through a slit in a piece of cardboard, while the prism itself is held in front of a white card; the resulting band of color is

called the spectrum. Which color is refracted (bent) the most? Which color is refracted the least? Hold a narrow strip of colored paper at various points in the spectrum and account for the apparent changes in the color of the strip.

3. Examine the light of a Welsbach burner, the light of a tungsten lamp, and the light of a carbon lamp, in turn, through the same piece of red glass; repeat the experiment with a piece of blue glass. (The lights should be of about the same candle power.) Observation? Conclusion?

Why do healthy people often look so pale and ghastly when seen by artificial light? Would red shades about the lights improve the situation? Explain.

## TOPICS FOR FURTHER STUDY AND INVESTIGATION

Fatigue of the eye. Gaze steadily at one spot in a small piece of bright yellow paper, pasted on a white card and held in the sunlight, until the eye becomes tired; then glance quickly toward the white part of the card. The tinge of color that suddenly appears is the complementary color to yellow. Explain. Try red, blue, and orange in turn. Why do yellow dress goods appear more brilliant when shown in the presence of blue goods than when shown by themselves?

Color blindness. Test your own sense of color with a numbered set of Holmgren's worsteds or with a Rumble's color disk. Successful candidates for the position of engineer or fireman on most of the great railways of the world are required to pass a severe test as to their ability to distinguish colors accurately and quickly. What are the requirements in your own state?

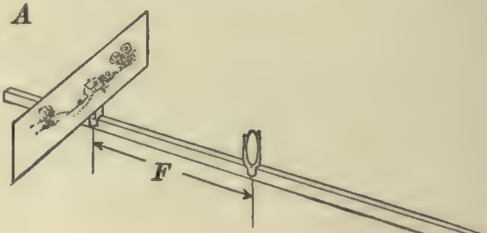
## 45. STUDY OF A LENS

### REAL IMAGE: CONJUGATE FOCI

**Apparatus.** Convex lens; simple optical bench, consisting of a meter stick, held in a horizontal position by two supports, and the following accessories: a lens holder, a white cardboard screen, a metal screen having a V-shaped opening covered with a wire netting, and an electric lamp or a gas jet.

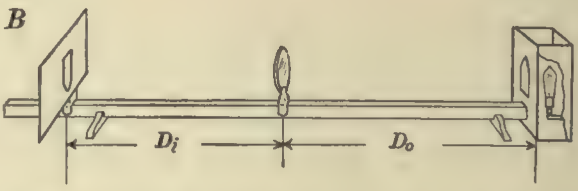
#### INTRODUCTION

A lens that is thicker in the middle than it is at the rim is called a convex, or converging, lens. Rays of light coming from a point 100 ft. or more away are practically parallel. Parallel rays falling on the surface of a convex lens are converged to a fixed point called the *principal focus* of the lens. The distance between the principal focus and the lens is the *focal length* of the lens. Two points situated on either side of a lens so that an object at one point will form an image at the other are called *conjugate foci* of the lens.



#### EXERCISE

*Object.* To determine the focal length of a given convex lens and to illustrate the law of conjugate foci.



*Method.* 1. Mount the lens and the cardboard screen on the meter stick, as in the illustration *A*; stand at the back of the room and point the lens toward a window; slide the lens along the meter stick, toward the screen or away from it, until a clearly defined image (picture) of a distant object outside the window appears on the screen. Note the distance on the meter stick between the screen and the lens, and record as the focal length *F* of the lens.

2. Mount the apparatus as in the illustration *B*. Focus the V-shaped opening on the screen. Is the image upright or inverted? larger or smaller than the object? Measure the distance ($D_i$) between the lens and the screen (image), and the distance ($D_o$) between the lens and the wire netting (object), and record. Move the lens toward the object and try again. Make several trials. Complete the tabular statement. Compare the results recorded in the last two columns. State the law of conjugate foci as a formula involving $D_o$, $D_i$, and $F$. What determines the size of the image in each case?

*(Form of Record)*

STUDY OF A LENS

CONJUGATE FOCI

(Sketch)

Focal length ($F$) .......... .........cm.

| $D_o$ | $D_i$ | $F$ | $\frac{1}{D_o} + \frac{1}{D_i}$ | $\frac{1}{F}$ |
|---|---|---|---|---|
| | | | | |

Law

Comments

## PROBLEMS

**1.** Explain the action of a burning glass in setting fire, by the direct rays of the sun, to a match or to a piece of paper. Try the experiment with a reading glass.

**2.** Suggest a method by which an enlarged image of a lighted candle may be thrown on a screen in a darkened room; illustrate by a sketch, drawn roughly to scale with the dimensions of all important parts carefully marked in inches. Design a simple stereopticon based on the same principle and explain the limits of the apparatus.

**3.** It is desired to project a lantern slide, 3 in. long, on a screen 50 ft. away. If the picture is to be 20 ft. long, what must be the focal length of the projecting lens?

**4.** What is the object of putting a convex lens in a bull's-eye dark lantern and in the end of an electric flash light?

## TOPICS FOR FURTHER STUDY AND INVESTIGATION

The camera. Set up a plate camera in the laboratory and examine its mechanism; procure a catalogue from the manufacturers of the instrument and make a careful study of all the parts of the apparatus. Remove the front lens; fasten an illustrated newspaper flat against the wall on one side of the laboratory in a good light, and focus the camera on it. Are all parts of the image as seen on the ground glass equally clear and distinct? How close can you bring the camera to the paper and still get a clear picture on the ground glass? What determines the limiting distance? Try the effect of the various stops or openings in the diaphragm. The smaller stops give greater definition but require longer exposure. Replace the front lens and again examine the image on the ground glass. What differences in the picture do you observe? Try the two lenses in combination. What conclusion do you reach as to the probable use of the separate lenses? Measure the focal length of each lens and measure the focal length of the combination. Look up the meaning of the following terms: *fixed focus lens*, *achromatic pair*, *rectilinear lens*, *anastigmatic lens*, *telephoto camera.*

Make a photograph of the illustrated newspaper or of a small building and paste the picture into your notebook. Write the following facts beneath the picture: Name of camera; focal length of lens; distance from lens to object; length of object; stop employed; time of exposure; name and speed of plate used; date; time of day; quality of light.

Stereopticon. If the school has a stereopticon, examine the instrument with care and learn to operate it.

Moving-picture machine. Find out all you can about the mechanism of a moving-picture machine, and report.

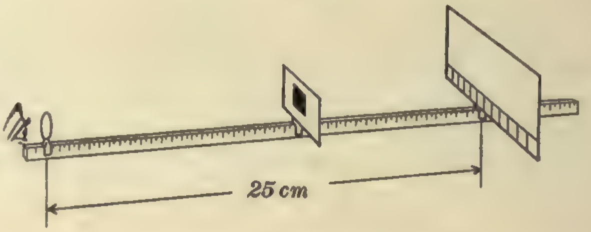
## 46. STUDY OF A LENS

### VIRTUAL IMAGE; MAGNIFYING POWER

**Apparatus.** Convex lens; lens holder; screen of white cardboard with a metric scale marked on it; screen of smaller size with a square centimeter printed in the center; screen holders; half-meter stick.

### INTRODUCTION

When $D_0$, in the lens formula $\frac{1}{D_0} + \frac{1}{D_i} = \frac{1}{F}$, is less than $F$, $D_i$ becomes negative; that is, the image falls on the same side of the lens as the object. In this case the image cannot be made to fall on a screen, but can be clearly seen *through* the lens, as in the case of a simple microscope or a reading glass. Measure the focal length of the convex lens (see exercise 45). Hold the lens over a page of your textbook, at a distance less than the focal length of the lens from the object, and observe the enlarged image of the print; measure $D_0$, the distance between the lens and the paper, and compute the value of $D_i$. Hold the lens in the same position again and, while looking through the lens, try to imagine the observed image located at a point as far below the lens as the computed value of $D_i$ shows it to be. What is the effect of increasing $D_0$? of decreasing $D_0$?



### EXERCISE

*Object.* To determine the magnifying power of a given convex lens.

*Method.* Mount the apparatus as in the illustration, the square-centimeter figure facing the lens and the white screen placed at a distance of 25 cm. (the distance of distinct vision) from the lens. Place one eye close to the lens and look through the lens at the picture of the square centimeter; with the other eye look around the lens at the white screen. Use both eyes at the same time; slide the object along the meter stick, toward the lens or away from it, until the image of the square centimeter appears to be clearly defined beside the metric scale on the second screen. Note the apparent length of the image; record as the magnifying power of the lens. Make several trials. Check your result from the formula: magnifying power $= \frac{25}{D_0}$, or magnifying power $= 1 + \frac{25}{F}$.

### PROBLEMS

1. Where will the image be formed if an object is held 5 cm. from a convex lens of 15 cm. focal length?
2. What is the magnifying power of a lens that has a focal length of 5 cm.?

### TOPICS FOR FURTHER STUDY AND INVESTIGATION

The simple microscope or botanical lens and some of its revelations.

Does a large lens magnify more than a small one? Why are simple microscopes frequently made with two or more lenses placed close together?

Linen-provers and their uses.

## 47. STUDY OF A TELESCOPE

### CONSTRUCTION; MAGNIFYING POWER

**Apparatus.** Convex lens (F. 35 cm.); convex lens (F. 5 cm.); concave lens (F. 5 cm.); lens holders; translucent screen and screen holder; half-meter stick; diaphragm (a piece of cardboard with a $\frac{1}{4}$-in. hole cut in it).

### INTRODUCTION

The real image (see exercise 45) formed by a convex lens may be treated precisely as though it were an object and magnified by a second lens so placed as to form an enlarged virtual image (see exercise 46) of the real image and therefore an apparent enlargement of the original object. A set of lenses combined for such a purpose forms a simple astronomical telescope and illustrates the principle upon which the big refracting telescopes of our great observatories are constructed. The lens farthest from the eye is called the objective and is often made very large (40 in. in diameter in the telescope of the Yerkes Observatory), for the purpose of gathering light to render the details of far-distant objects visible to the keen-eyed astronomer; the lens next the eye is called the eyepiece and is often made with a very short focal length ($\frac{1}{10}$ in.), for the purpose of increasing the magnifying power of the telescope — in some cases to 1000 diameters.

In the spyglass, or terrestrial telescope, two additional lenses are inserted between the objective and the eyepiece, for the purpose of making the image appear right side up.

The opera glass has a concave, or diverging, lens for an eyepiece; by this device the converging rays from the objective are made to diverge sharply just before the real image is formed, and the result is a virtual image that is upright and enlarged.

### EXERCISE

*Object.* To show how a celestial telescope may be assembled from two convex lenses, and to illustrate the opera glass, or Galilean telescope.

*Method.* 1. Mount the two convex lenses on the half-meter stick, the short-focus lens near one end for an eyepiece and the long-focus lens 40 cm. away for an objective; mount the screen between the two lenses. Stand at the back of the room and point the objective toward a window; slide the screen along the meter stick until a clearly defined image of some distant object outside the window appears on the screen. Now focus the eyepiece on the screen until the image of the distant object which appears on the back of the screen can be seen clearly when the eye is placed close to the lens. Remove the screen and observe that the image can still be seen through the eyepiece.

Focus the telescope upon some object hanging on the walls of the laboratory; compare the size of the image seen through the telescope with the size of the object when seen at the same time with the unaided eye, and estimate the magnifying power of the instrument. Check your results by the formula: magnifying power of telescope $= \frac{F \text{ (focal length of objective)}}{f \text{ (focal length of eyepiece)}}$.

2. Construct a crude opera glass from the materials at hand, using the long-focus lens (or the lens used in exercise 45) for an objective and the concave lens for an eyepiece. The distance between the eyepiece and the objective must in this case be made equal to the difference between the focal lengths of the two lenses. Focus the instrument on a distant object and estimate its magnifying power. Better definition can be secured if a diaphragm (an opaque card with a $\frac{1}{4}$-in. hole cut in it) is mounted near the eyepiece.

## TOPICS FOR FURTHER STUDY AND INVESTIGATION

The equatorial telescope and some of the wonders revealed by the instrument.

The test of an opera glass. A first-class instrument should show a good illumination (brilliant image), good definition (clean-cut image), and fair magnification (at least 2 diameters), and should be free from chromatic aberration (color fringes about the image). It is desirable, moreover, that the distance between the centers of the eyepieces (interocular distance) should be the same as the distance between the pupils of the owner's eyes; otherwise the two fields of view as presented to the two eyes do not coincide, and two circles are seen instead of one. Test the opera glass assigned you by the instructor for all the points mentioned above, and report in writing under the heading Study of an Opera Glass: Report. Illustrate your report by a drawing showing the principle upon which the instrument is constructed, and state the name and make of the instrument examined.

What elements in the construction of an opera glass determine (1) the amount of illumination, (2) the definition, (3) the magnification, and (4) the freedom from color?

The prism binocular.

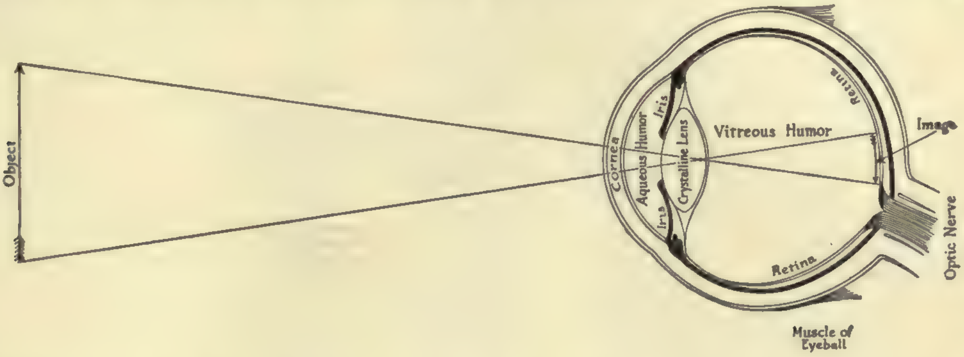
# 48. STUDY OF THE EYE

## DEFECTS OF VISION: TEST

**Apparatus.** Vision chart (Snellen's test letters); divided disks and diamond type, shown as inserts in the text below.

### INTRODUCTION

The human eye (see illustration) resembles a camera in many respects, being fitted up with a series of convex lenses (cornea, aqueous humor, crystalline lens, vitreous humor) to form a clear image of a distant object on the retina (screen at the back of the eye), a shutter (eyelid) to exclude the light when the instrument is not in use, an iris diaphragm (the iris) to regulate the amount of light entering the instrument, and a great variety of dainty bits of mechanism (tiny muscles) to move the apparatus about and to point it toward the object. But in its normal state the eye is a far more wonderful instrument than the camera. In the first place, it is automatically focused, for distant and near objects, not by a to-and-fro movement of the lens, as in the camera, but by a *change in the focal length of the crystalline lens itself* — a device that man has never been able to copy. Again, all surfaces exposed to the air are kept clean and moist by an automatic process of sponging, for, by the act of winking, the eye is washed with a salty fluid every few seconds. A complete study of this wonderful instrument would be intensely interesting and decidedly worth while, but we must confine ourselves for the present to a few simple tests for possible defects in our own sense organs. The most common of these defects are the following:



1. *Nearsightedness* (myopia), due usually to the fact that the retina is too far from the cornea, so that the rays of light from a *distant* object are brought to a focus in *front* of the retina, and the person suffering from this defect of the eye can see clearly only those objects which are close to him or within a distance of about 12 in. from the eye. A *concave* lens is needed to offset, in part, the effect of the crystalline lens and to push the image back to the retina.

2. *Farsightedness* (hypermetropia), due usually to the fact that the retina is too close to the cornea, so that the rays of light from an object which is *near at hand* are brought to a focus *behind* the retina, and the person suffering from this defect of the eye can see clearly only those objects which are more than 18 in. from the eye. An extra *convex* lens is needed to bring the image back to the retina.

3. *Astigmatism*, due to a defect in the curvature of the cornea or of the crystalline lens, so that rays of light coming from certain lines, at right angles to each other, are not all brought to the same focus; the image is therefore not sharply defined, and the person suffering from this defect of the eye cannot see anything *distinctly*, though he is usually quite unaware of the fact until his eyes

have been tested by an oculist and the proper lenses adjusted. A *cylindrical* lens, adapted to the angle of astigmatism in each case, may be used to clear up the image.

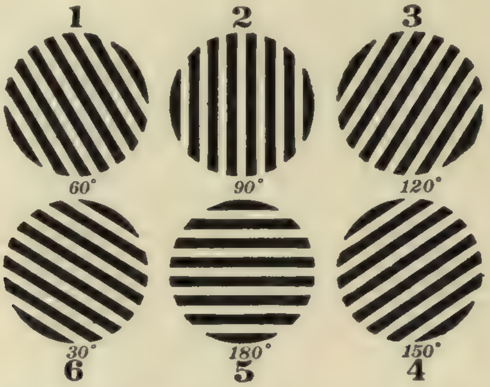
These defects of vision place a serious strain upon the nervous system and are often the unsuspected cause of headache, indigestion, dizziness, and even of apparent dullness. When they are found to exist in any marked degree, a competent oculist should be consulted, and his advice should be followed.

### EXERCISE

*Object.* To test the eye for astigmatism and for acuteness of vision.

*Method.* 1. *Astigmatism.* Cover the right eye by placing a card in front of it, and with the left eye examine the divided disks (see illustration), placed upright and 15 in. away.

Do all the disks appear equally *black* and *distinct*? If not, note which one appears to be the clearest, and record, by number, together with the observed angle of astigmatism (as shown by the dip of the lines in the selected disk and indicated in degrees by the small figures beneath the disk). Test the right eye in the same way; record. If glasses are worn, they may be kept in place during the test, and a separate test may be made later, if desired, without the glasses.



Note. A more delicate test for astigmatism, usually employed by the professional oculist, consists in the use of a special disk (resembling the dial of a clock) placed 20 ft. from the observer.

2. *Acuteness of eyesight.* (*a*) *Distant vision.** Hang the Snellen test letters in a good clear light (side light preferred), on a level with the head. Stand 20 ft. from the letters, the left eye being covered with a card held firmly against the nose without pressing on the covered eye, and read from left to right the smallest letters you can see on the card. Make a note of the line read.

*Directions for recording.* You will notice that there is a number over each line of the test letters, which shows the distance in feet at which these letters should be read by the normal eye. From top to bottom the lines on the card are numbered 50, 40, 30, and 20 respectively. At a distance of 20 ft. the average normal eye should read the letters on the 20-foot line, and if this is done easily, or with the exception of one or two letters, the vision may be noted as $\frac{20}{20}$, or normal. In this fraction the numerator is the distance in feet at which the letters are read, and the denominator is the number over the smallest line of letters read. If the smallest letters which can be read are on the 30-foot line, the vision will be noted as $\frac{20}{30}$; if the letters on the 40-foot line are the smallest that can be read, the record will be $\frac{20}{40}$; if the letters on the 50-foot line are the smallest that can be read, the record will be $\frac{20}{50}$.

If you cannot see the largest letters (the 50-foot line), approach slowly until you find a distance at which you can see them. If 5 ft. is the greatest distance at which you can read them, the record will be $\frac{5}{50}$ ($\frac{1}{10}$) of normal. Record.

Test the left eye, the right eye being covered with the card, and record the result as before.

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* Adapted from Statutes of Massachusetts, Acts of 1906.

If your vision with either eye is less than $\frac{20}{30}$, if your eyelids are habitually red or inflamed, or if there is pain in the eyes or in the head after reading, your eyes need medical attention.

(*b*) *Near vision.* To find the far point for near vision, cover the left eye and record the farthest distance at which the diamond type can be seen. Test the left eye in the same way, and record. To find the near point, proceed in the same manner, and record the shortest distance at which the diamond type can be seen with each eye. The visual range of the normal eye for pupils of high school age, when engaged in reading diamond type, usually extends from about 4 in. to about 20 in.; in any event the diamond type should be read easily and without conscious strain at a distance of about 10 in. (25 cm.)

**If your eyes are strictly normal, you should be able to read this type easily, and with either eye separately, at a distance of about 10 in. (25 cm.). The eye is one of the most delicate organs of the body and one of the most abused. It is a wonder that some people retain their sight as long as they do. If you have reason to think that your eyes need special attention, consult a competent oculist or some reputable physician who has made a special study of the eye, and follow his advice. Do not intrust your eyes to tradesmen or to spectacle peddlers.**

DIAMOND TYPE

(*Form of Record*)

### STUDY OF THE EYE

### MY OWN EYES — VISION TEST

Name .................................... Age .................................... Date ....................................

*Astigmatism*

Clearest disk . . . . . . . . . . . . . . . . Right eye, No.[1] ...................... °
Left eye, No. ...................... °

*Acuteness of eyesight*

Distant vision (using Snellen's test type) . . . . Right eye ..............................
Left eye ..............................

Near vision (using diamond type). . . . . . . Right eye ..............................
Left eye ..............................

*Comments*

*Conclusion*

[1] If all of the disks appear black and equally distinct, place a dash here.

# 49. STUDY OF A PERMANENT MAGNET

## MAGNETIC LINES OF FORCE

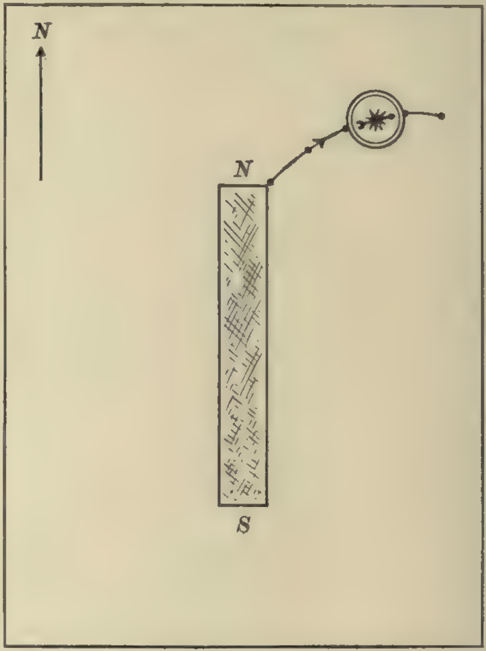
**Apparatus:** Two bar magnets; U-magnet; soft-iron ring; magnetic compass; iron filings.

### EXERCISE

*Object.* To investigate the field of force about a permanent magnet.

*Method. Preliminary.* Bring the *N*-pole (the north-seeking pole) of a bar magnet slowly up to the magnetic compass and observe the effect upon the compass needle; substitute the *S*-pole (the south-seeking pole) of the bar magnet and repeat the experiment. Conclusion? Given a magnetic compass and a magnet, how would you proceed to determine the polarity (position of the *N*-pole and the *S*-pole) of the magnet?

1. Place the small compass on the table in the center of a sheet of paper; turn the paper around until its longest edges are parallel to the magnetic needle (the bar magnets being several feet away) and fasten it to the table with thumb tacks. Place an arrow pointing north in one corner of the paper and remove the compass. Lay a bar magnet, with its north-seeking end pointing north, in the center of the paper; outline the perimeter of the magnet with the point of a sharp pencil and indicate its poles by the letters *N* and *S*.



Make a dot on the paper near one end of the magnet. Place the compass on the paper beside the magnet; move the compass about until one end of the needle points to the dot on the paper, and make a dot opposite the other end of the needle. Move the compass again until the end of the needle that pointed to the first dot points to the second dot, and make a third dot at the opposite end of the needle. Continue in this way until you reach the edge of the paper, or the south end of the magnet. Through these several dots draw a continuous line (see illustration) in the form of a smooth curve, and indicate the direction of the north-seeking end of the needle by a succession of arrows. The line thus drawn represents a *magnetic line of force.*

Beginning at different points about the bar magnet, trace a dozen or more magnetic lines of force on either side of the magnet, and report the result. Turn the magnet about until its south-seeking end points toward the north, and (making use of a second piece of paper) repeat the experiment. Paste the two sheets in your notebook beside a description of the method by which the figures were produced, and be ready to discuss the results of the experiment.

2. Place a thin sheet of cardboard over the bar magnet and sprinkle it with iron filings. Tap the paper gently and watch the iron filings as they gradually adjust themselves along the magnetic lines of force. Sketch the magnetic field of force as outlined by the iron filings, placing arrows here and there to indicate the direction of the magnetic flux as pointed out by the north-seeking end of a compass needle placed in succession at the designated points, and compare the result with the corresponding drawing made by use of the compass above. Place the two magnets end to end,

about an inch apart and with like poles facing each other; sprinkle with iron filings and again sketch the magnetic field of force; repeat the experiment with unlike poles facing each other. State the law of attraction and repulsion for the poles of a bar magnet. Sketch the magnetic field of force about a U-magnet, giving special attention to the space between the magnetic poles; place the soft-iron ring midway between the two poles of the U-magnet and again sketch the magnetic field of force about the magnet.

## TOPICS FOR FURTHER STUDY AND INVESTIGATION

Variation of the needle. Determination of true north. Magnetic induction. Effects on the magnetic field of neighboring masses of iron.

Practical uses of permanent magnets. The field magnets of the magneto. Magnetic brakes, or dampers, as used in the watt-hour meter and in the speedometer (see catalogues).

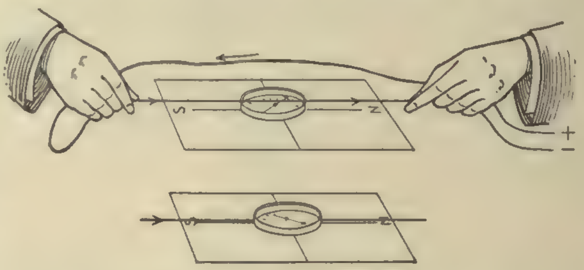
# 50. STUDY OF AN ELECTRIC CURRENT

## OERSTED'S PRINCIPLE

**Apparatus.** Magnetic compass; insulated wire; source of electricity (battery or low-voltage dynamo).

### EXERCISE

*Object.* To determine the effect of an electric current on a compass needle and to learn how to make use of the facts observed to find the direction of an electric current flowing through a given wire.



*Method.* Connect the ends of the wire, from which the insulation has been previously removed for the space of half an inch or more, to the source of electricity. By consultation with your instructor determine the direction of the current flowing in the wire. (*Note.* The current furnished by a zinc-carbon cell flows from the carbon to the zinc, through the connecting wire, outside the cell, and from the zinc to the carbon inside the cell.)

Place the compass on the table; turn the box around until the *N* point of the compass card is directly under the north-seeking end of the compass needle. Bring a section of the wire carrying the electric current steadily down over the compass (see illustration), keeping the wire all the while parallel to the north-and-south line of the earth, until the wire finally comes to rest upon the top of the compass, and observe the effect on the compass needle. Place the compass over the wire, the electric current running in the same direction as before, and again observe the effect of the current on the needle. Reverse the current by changing the connections, and repeat the experiment. Record your results in the form of four simple sketches, showing in each case the position of the compass and the wire carrying the electric current, with arrows correctly placed to indicate the direction of the current and the corresponding deflection of the compass needle; use a dotted line to show the wire passing under the compass and a full line to show the same wire passing over the compass. Make up a general rule showing the connection between the direction of the current and the deflection of the north-seeking end of the needle, and on this rule as a basis frame a correct answer to each of the following questions:

A current of electricity running over a compass needle lying in the magnetic meridian deflects the north-seeking end of the needle toward the east; in what direction is the current flowing? The north-seeking end of a compass needle placed over a wire carrying a current of electricity and lying in the magnetic meridian is deflected toward the west; in what direction is the current flowing? What would be the effect on the magnetic needle in the last question if an alternating current of 60 cycles were to be used in place of the direct current?

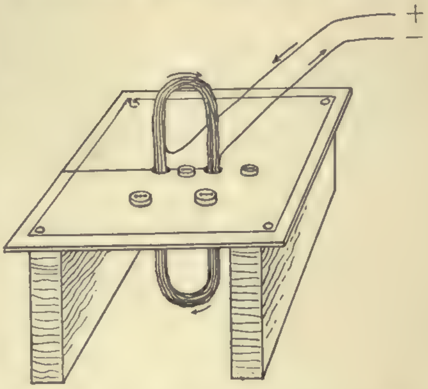
Give terse directions for finding (by means of a magnetic compass) the direction of an electric current flowing in a given wire. Look up the thumb-rule, if convenient, and compare the results of your experiments with the standard statement.

Loop the wire several times around the compass in such a way that the electric current may flow from north to south above the needle and from south to north below the needle; turn on the current and compare the effect with that produced by a single turn of wire.

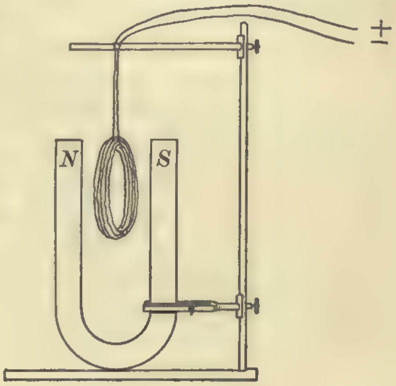
Write up the exercise in the form of a condensed narrative illustrated by a series of sketches, as suggested, and report.

Magnetic lines of force about a coil of wire carrying a current of electricity. Thread a coil of insulated wire through two holes in a piece of cardboard and mount the apparatus as shown in the illustration; connect the exposed ends of the wire to a source of electricity (battery or low-voltage dynamo), and by means of a magnetic compass investigate the magnetic field of force about the sides of the coil and through the center of the coil (see Ex. 49). Reverse the direction of the current and repeat the experiment. Write out a statement showing the relation between the direction of the electric current flowing around the coil and the direction of the magnetic lines of force passing through the coil.

Suggest two methods by which the strength of the magnetic field of force surrounding the coil of wire may be increased.



Suspend a coil of fine wire (No. 30, insulated) between the poles of a horseshoe magnet (see illustration) in such a manner that, while the plane of the coil is parallel to the line joining the poles of the magnet, the coil may be capable of rotating freely about its vertical axis, and send a current of electricity through the coil. Observation? Reverse the current. Observation? Explain. *Suggestion:* Consider the direction of the magnetic lines of force running (1) between the two poles of the horseshoe magnet, (2) through the center of the coil of the wire, and apply the general principle that these magnetic lines of force have a tendency to coincide and to run in the same direction through any given point.



The simple galvanoscope.

The D'Arsonval galvanometer.

The commercial ammeter.

The electric motor.

## 51. STUDY OF AN ELECTROMAGNET

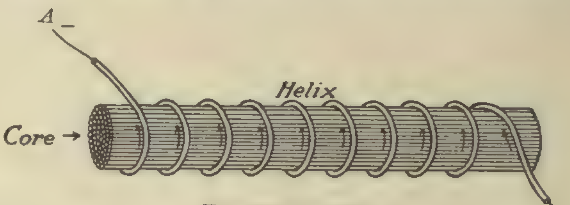
### CONSTRUCTION; POLARITY

**Apparatus.** Bundle of soft-iron wire, 3 or 4 in. in length and ¼ in. in diameter; U-shaped core of an electromagnet; 15 ft. of No. 23 cotton-covered copper wire; magnetic compass; iron filings; source of electricity (battery or low-voltage dynamo).

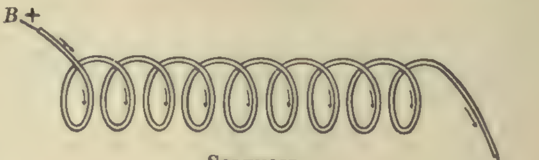
### EXERCISE

*Object.* To illustrate the construction of an electromagnet and to determine the method of fixing in advance the polarity of the core.

*Method.* 1. Leaving the ends exposed, wind the insulated wire about the bundle of soft-iron wire as thread is wound on a spool. Attach the exposed ends of the wire to the leads from the battery or dynamo and close the circuit. Dip one end of the electromagnet thus made (see illustration *A*) into the iron filings. Observation? Open the circuit. Observation? Conclusion? Lay the electromagnet on the table and again close the circuit. By means of the magnetic compass, placed under one of the connecting wires at a point some distance from the electromagnet, determine the direction of the electric current in the wire (see Ex. 50), and by tracing the circuit from this point determine the direction of the current about the core of the electromagnet; determine the polarity (*N* or *S*, see Ex. 49) of either end of the core. Reverse the current and again determine the polarity of the core. Observation? Conclusion? Make a drawing of a typical electromagnet; indicate by arrows the direction of the current in the helix and show by appropriate letters the resulting polarity of the core.



ELECTROMAGNET

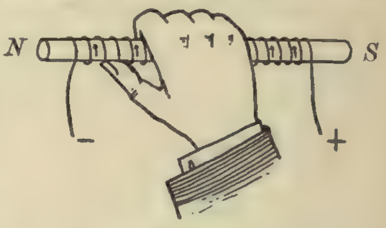


SOLENOID

2. Remove the soft-iron core from the electromagnet and lay the helix (see illustration *B*) down on the table; send a current of electricity through the helix (now called a solenoid) and by means of the magnetic compass determine the polarity of the ends of the solenoid; reverse the current and again test the polarity of the solenoid. Conclusion? Of what use is the soft-iron core of an electromagnet?

3. Wind the soft-iron core of the U-magnet in such a manner that one end of the U shall be an *N*-pole and the other end shall be an *S*-pole.

*Polarity rule.* If the palm of one's right hand be placed against the side of an electromagnet (see illustration), or against the side of a solenoid, in such a manner that the fingers point in the direction of the electric current passing through the windings, the thumb will point in the direction of the north-seeking pole of the electromagnet or the solenoid. Are your sketches in agreement with the rule?



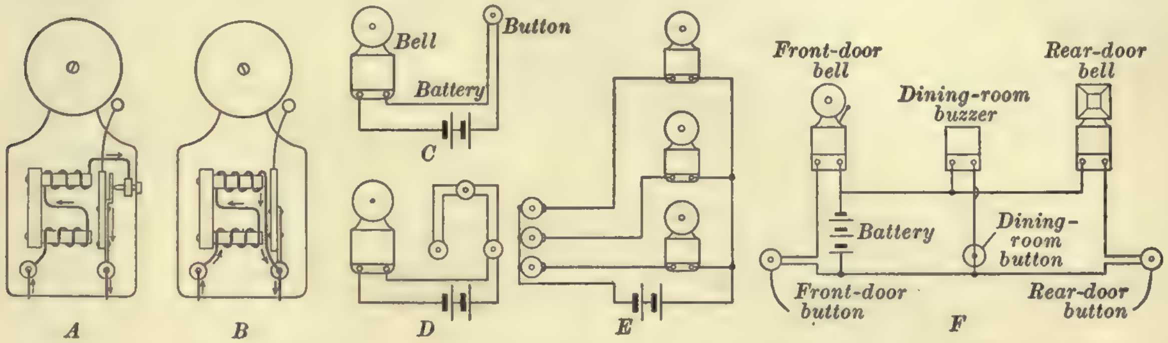
*Optional.* (1) By what two methods may the strength of an electromagnet be increased? Prove, by experiment, the correctness of your answer. (2) Compare the magnetic field of force surrounding a commercial electromagnet, in action, with the magnetic field of force surrounding a permanent magnet of the same form. What advantages has an electromagnet over a permanent magnet?

Write up the exercise in the form of a simple narrative: illustrate your experiments by a series of simple drawings and make a clear statement of your various observations and conclusions.

The commercial electromagnet. Remove the electromagnet from an old electric bell, if one is to be had about the house or the laboratory; energize the magnet by sending an electric current through it, and test its lifting power; increase the strength of the current and again test the lifting power of the magnet.

The Morse telegraph. Examine a learner's instrument; trace the electric current through the various parts of the apparatus (the sounder and the key); connect a dry cell to the binding posts and describe the action of the apparatus as the circuit is alternately opened and closed by means of the key or the circuit-breaker (small lever beneath the knob of the key). See Appendix for the Morse code. The relay.

Electric bells. Remove the cover from an ordinary house bell; by help of the diagram *A* (see illustration below), and keeping in mind the fact that the iron base may form a part of the circuit, trace the circuit through the various parts of the apparatus; connect a dry cell and a push button in series with the bell (diagram *C*) and account for the continuous ringing of the bell as the push button is held down. Study the diagram *B* of the single-stroke bell and determine what changes in the apparatus are necessary to convert a vibrating bell into a single-stroke bell. Make up as many of the connections shown in diagrams *D*, *E*, and *F* as you can with the apparatus at hand, and test each; to prevent unnecessary jangling of bells during the tests, muffle each hammer with a tuft of cotton or a piece of paper, or use small 1 c.p. electric battery lamps in place of the electric bells. Design a bell circuit to accomplish a specified purpose, and show how you would practice economy in the use of wire. Study the bell circuits in your home; make a sketch of the connections as you conceive these to be, and report.



Annunciators: principle; connections.

Bell-ringing transformers.

Master clocks and program clocks: principle; connections.

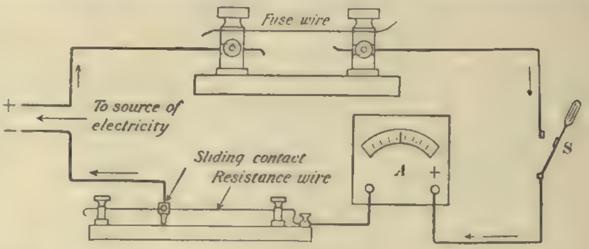
# 52. STUDY OF A FUSE

## CAPACITY; USES

**Apparatus.** Fuse block, made by inserting two combined English and American binding posts, 1⅞ in. apart or 1½ in. in the clear, in a hard-wood base; spool of 2-ampere fuse wire; ammeter, 0–15 amperes; source of electricity (2 dry cells, storage cell or low-voltage dynamo); rheostat for regulating the strength of the current; watch.

### INTRODUCTION

The rate, in gallons per second, at which water flows through a given water pipe is determined by (1) the pressure behind the water, and (2) the resistance offered by the pipe and the faucet; an increase in pressure or a decrease in resistance, usually caused by a wider opening of the faucet, increases the rate of flow. Similarly, the rate, in amperes, at which electricity flows through a given conductor is determined by (1) the pressure, in volts, behind the current, and (2) the resistance, in ohms, of the circuit. An increase in pressure (E.M.F.) or a decrease in resistance, usually accomplished by gradually cutting out a fixed resistance, increases the rate of flow. Resistance to motion tends, in either case, to generate heat.



The overheating of any part of an electric circuit by an excessive rate of flow, caused by a short circuit or by a wrong connection, is usually guarded against by the insertion, in the circuit, of a fuse designed to shut off the current, by opening the circuit, at a given rate of flow in amperes. Fuses (alloys of bismuth, antimony, and lead) are made in various sizes and are rated in amperes, to indicate the strength of current at which they may be expected to blow, or to melt and break the circuit; this rating for open fuses is in reality far below the actual point of fusion and must be treated accordingly. Inclosed fuses are much more reliable than open fuses.

The United States government requires that fuse wire, when tested in 1-inch lengths and in a horizontal position, shall carry continuously 50 per cent overload and fuse on 100 per cent overload in one minute.

*An ammeter in circuit should be protected by a fuse of such a size or capacity that the fuse will be sure to blow before the ammeter-range in use can be overloaded.*

### EXERCISE

*Object.* To determine the current strength required to melt a given fuse and to compare the result with the rated capacity of the fuse.

*Method.* Stretch a piece of fuse wire between the two binding posts of the fuse block and secure it firmly in place by clamping the ends of the wire beneath the copper washers of the English binding posts. Arrange the apparatus as in the illustration, but do not turn on the current until your connections have been approved by the instructor.

Set the rheostat to give a small current; close the switch and read the ammeter; increase the current by small stages, pausing half a minute at each stage, until the fuse blows; record the highest reading of the ammeter, with the name and rating (stated capacity) of the fuse; record the temperature of the room. Compute the percentage ratio between the blowing current and the rated capacity of the fuse. What is the maximum current strength, in amperes, that can be carried safely by the fuse wire tested? Replace the fuse by a fresh piece of fuse wire of the same size; raise the strength of the current quickly to the blowing point of the first fuse, and note the time in seconds between the first rush of the current and the blowing of the fuse. When used in 1½-inch lengths, against a sudden rush of what minimum number of amperes would the given fuse wire furnish protection to an instrument in series with the fuse? Try the effect of varying the length of the fuse. Observation? Conclusion? Would a change in the temperature of the room be likely to effect the blowing-point of the fuse? Explain.

Compare your results with those obtained by the other members of the class; compute the average.

Illustrate your report by a sketch showing the apparatus used and the electrical connections.

## TOPICS FOR FURTHER STUDY AND INVESTIGATION

Commercial fuses. Look up the subject of cut-outs in the trade catalogues belonging to the laboratory, in a book of underwriters' rules, or in some handbook on house-wiring, and note the various kinds of fuses in general use, with their rated capacities; locate as many kinds of fuses as possible in the principal circuits of the laboratory or in the lighting circuits of the school building; note rated capacities and report with a simple description, illustrated by a sketch, of each kind of fuse discovered. Under the direction of the instructor, test the capacity of a given inclosed fuse and compare the result with the rated capacity of the given fuse as marked on the case.

Why are fuses required by law in all house-lighting circuits? In experimental work, why should care be taken to see that in every line containing an ammeter and an unknown load a fuse of suitable capacity is inserted before the circuit is closed?

Tin-foil fuses. By pasting a narrow strip (⅛-in. wide) of the thinnest tin foil to be had in the market upon a piece of writing paper, construct a fuse and test its capacity; from the experience thus gained construct a second fuse of 10-ampere capacity and test it for accuracy of rating. (*Note.* Shield your eyes from the fuse and be on your guard against overloading the ammeter.) How would you proceed to construct a fuse, from the materials at hand in the laboratory, if the estimated load is to be 15 amperes?

See Monograph B–5, published by the Weston Electrical Instrument Co., Newark, N.J.

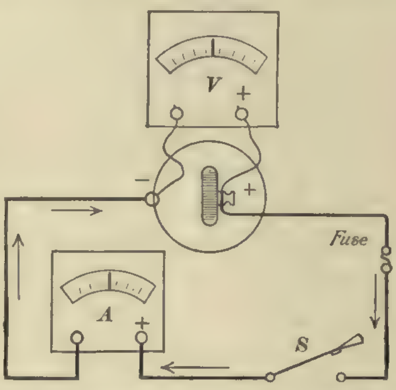
# 53. STUDY OF A VOLTAIC CELL

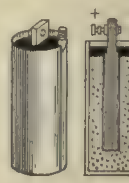
## DRY CELL; DANIELL CELL

**Apparatus.** Dry cell; Daniell cell, or gravity cell; ammeter 0–30, 0–3 amperes; fuse; voltmeter, 0–3 volts; switch; timepiece.

### INTRODUCTION

Primary cells may be classed as open-circuit cells or as closed-circuit cells, according as they furnish, when connected through an external circuit of low resistance, a constant or a variable current. The dry cell and the Daniell cell are typical of these two classes of cells.





Dry Cell

Break open a disused dry cell and examine its parts. The metal case is made of zinc; the solid black cylinder is usually composed of pulverized carbon, mixed with molasses or some other adhesive material which will readily carbonize, and solidified by hydraulic pressure at a high temperature; the paste surrounding the cylinder is usually composed of pulverized carbon, or of coke, mixed with black oxide of manganese and moistened with a solution of sal ammoniac and water; the inner surface of the zinc is protected by a sheet of unglazed paper which takes the place of the porous cup in the Daniell cell and reduces local action. When the cell is at work, the current flows from the carbon (+ pole) through the external circuit to the zinc (− pole) and thence through the cell back to the carbon.

Examine the parts of a Daniell cell. The outer jar should contain a solution of copper sulphate (blue vitriol) and a cylinder of copper; the porous cup should contain a strip of zinc and a dilute solution (1 acid, 20 water) of sulphuric acid and water. When the cell is at work, the current flows from the copper (+ pole) through the external circuit to the zinc (− pole) and thence through the cell back to the copper.

### EXERCISE

*Object.* To investigate the behavior of (1) a dry cell and (2) a Daniell cell when supplying a current through an external circuit of comparatively low resistance.

*Method.* 1. *The dry cell.* Using the *higher range*, 0–30, of the ammeter, connect the apparatus as in the illustration, but do not close the circuit through the ammeter until your connections have been approved by the instructor.

Note. Ammeters are delicate instruments and must be handled with care, for a wrong connection may easily result in a burned-out coil and the utter ruin of the instrument. Never close the circuit through an ammeter until you are sure that enough resistance has been introduced, in series with the instrument, to insure the ammeter against an excess of current strength. If the needle fails to move, or if it moves in the wrong direction, *first* open the circuit at the switch, and *then* reverse the connections at the terminals of the ammeter leads. The ammeter in the illustration is shown protected by a fuse (see Ex. 52). If preferred, a short piece of German silver wire No. 30 (to limit the strength of the current) may be used in place of the fuse; no such device will be needed in the second part of this exercise, as the internal resistance of the Daniell cell cuts down the current strength to a comparatively small amount.

It is good practice, in using an ammeter or a voltmeter having more than one range, first to make connection to the higher range, and then, if the reading warrants it, to change to the lower range.

*a. Polarization.* Read the voltmeter. Record the result as the electromotive force (E.M.F.) of the cell. See *Form of Record.* Close the switch *S* and read the ammeter. Record the result as the current strength of the cell. Keep the circuit closed for half an hour or until the current strength becomes constant. At intervals of five minutes, open the switch for an instant and note the electromotive force of the cell. Read the ammeter once in every three minutes, and record.

*b. Recovery.* Open the circuit. Read the voltmeter once in every three minutes for a period of half an hour or until the E.M.F. becomes constant, and record. At intervals of five minutes close the switch for an instant and record the current strength of the cell. Conclusion?

The effects observed are due to a change in the internal resistance of the cell, caused by local action. The first effect noted is called polarization, and the second, depolarization. The cell is said to polarize on a closed circuit and to recover on an open circuit. Is a dry cell to be classed as an open-circuit cell or as a closed-circuit cell? Would such a cell be suitable for operating an electric fan? Explain.

2. *The Daniell cell.* Substitute the Daniell cell for the dry cell (the copper is the + pole). Use the lower range of the ammeter and repeat the experiment. Conclusion? Should a Daniell cell be classed as an open-circuit cell or as a closed-circuit cell? Would such a cell be suitable for a laboratory experiment requiring a steady current?

Which cell has the larger current strength (amperage)? Which cell has the larger E.M.F. (voltage)? Plot curves between time and current strength, to show the action of each cell on a closed circuit.

(*Form of Record*)

STUDY OF A VOLTAIC CELL

Dry cell. 1. On closed circuit — polarization.

| Time (*Hr. and Min.*) | Current strength (*Amperes*) | Electromotive force (E.M.F.) (*Volts*) |
|---|---|---|
| | | |

2. On open circuit — recovery.

*Conclusion.*

Answers to questions.

## TOPICS FOR FURTHER STUDY AND INVESTIGATION

The chemistry of a voltaic cell; care of dry cells.

What is meant by the internal resistance of a cell?

Why does an old dry cell give less current than a new cell? Why does a dry cell deteriorate ("run down") in time, even if it is not used? Why are flash-light batteries dated by the manufacturers?

The Leclanché cell: construction; operation.

The gravity cell: construction; operation.

Combinations of cells to form a battery: series and parallel connections.

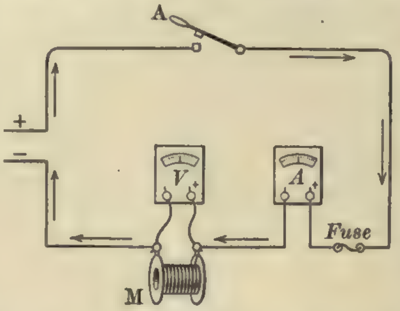
## 54. STUDY OF OHM'S LAW

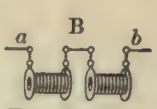
### MEASUREMENT OF RESISTANCE

**Apparatus.** Three coils of Weston alloy, German silver, or Ia Ia wire — two, M and N, of known resistance and one, X, of unknown resistance; ammeter, 0–15 amperes; voltmeter, 0–15 volts; fuse block and 15-ampere fuse; switch; source of electricity (low-voltage dynamo or storage battery).

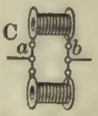
### INTRODUCTION

To Dr. G. S. Ohm, of Erlangen, Bavaria, is to be attributed the epoch-making discovery, developed in 1827, of the exact relation existing between the strength $I$ of an electric current, the potential difference $E$ behind the current, and the resistance $R$ of the circuit. Ohm's law, the cornerstone of modern electrical engineering, may be stated as follows: Current strength $I$ in amperes $= \dfrac{\text{potential difference } E \text{ in volts}}{\text{resistance } R \text{ in ohms}}$; that is, $I = \dfrac{E}{R}$, or amperes $= \dfrac{\text{volts}}{\text{ohms}}$. Ohm's law may be stated again as follows: The difference in potential $E$ between two points in an electric circuit is equal to the product of the current strength $I$ and the resistance $R$ of that portion of the circuit lying between the two points; that is, $E = I \times R$, or volts = amperes × ohms.

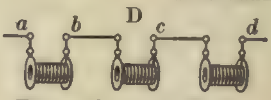




Two Coils in Series



Two Coils in Parallel



Three Coils in Series

*Definition.* The standard ohm is defined as the resistance, at 0° C., of a column of pure mercury 1 sq. mm. in cross section and 106.3 cm. long. The resistance of 10 ft. of No. 30 copper wire is approximately 1 ohm.

### EXERCISE

*Object.* To illustrate Ohm's law and to apply the principle involved to the determination of the resistance of a conductor.

*Method.* 1. *Ohm's law.* Connect the apparatus as shown in the illustration A, the ammeter in series with the coil M of known resistance, and the voltmeter in parallel with the coil; but do not close the circuit until your connections have been approved by the instructor. Close the switch; record the reading of the ammeter and the reading of the voltmeter; record the resistance, in ohms, of the coil; divide the volts by the ohms and compare the result with the reading of the ammeter. Substitute the coil N for the coil M and repeat the experiment. Conclusion?

Note. Voltmeters are delicate instruments and must be handled with care, for from the nature of their construction they are especially subject to an accidental burn-out under an excessive overload, and a voltmeter cannot be protected from injury, as an ammeter can, by the use of a circuit-breaker or a fuse. Care must be taken in each case to use a voltmeter range of sufficient capacity to measure the voltage under consideration. When in doubt as to which range to use, start with the highest range available and then, if the reading warrants it, change to a lower range. If the needle fails to move or if it moves in the wrong direction, reverse the connections (at the circuit end, not at the meter).

For suggestions concerning the use of an ammeter, see Note under Ex. 53.

2. *Resistance by the volt-ammeter method.* This is the usual commercial method, giving approximate values only. For the sake of greater precision the Wheatstone-bridge method (see Ex. 55) is commonly employed in the laboratory.

Connect the apparatus as before, using the coil X in place of the coil M; read the voltmeter and the ammeter; by the aid of Ohm's law compute the resistance of the coil X and report the result.

3. *Conductors in series.* Connect the two coils, M and N, in series, as shown in the illustration B; determine by the volt-ammeter method the joint resistance of the two coils connected in series, and compare the result with the sum of the resistances taken separately. Conclusion? (*Suggestion:* Connect the leads of the voltmeter to the outer extremities of the two coils at the points *a* and *b*.) Try three coils in series (see illustration D). Record.

4. *Conductors in parallel.* Connect the two coils, M and N, in parallel, as shown in the illustration C. Determine the joint resistance of the two coils connected in parallel, and compare the result with the resistance of each of the two coils taken separately. Conclusion? (*Suggestion:* Connect the leads from the voltmeter to the extremities of the two coils at the points *a* and *b*. Designate the resistance of the coil M by the symbol $R'$, the resistance of the coil N by the symbol $R''$, the combined resistance of the two coils by the letter $R$, and compute the value of each of the following quantities: $\frac{I}{R}$ and $\frac{I}{R'} + \frac{I}{R''}$. Compare the results.) Write up the exercise in good form, and report.

### PROBLEMS

**1.** An incandescent lamp on a 110-volt circuit carries a current of ½ ampere. What is the resistance, in ohms, of the lamp?

**2.** A current of .1 ampere, when passed through the human body, is likely to prove fatal. If the resistance of an average man varies from 3000 ohms to 4000 ohms, what voltage may be regarded as dangerous?

**3.** The separate resistances of two wires are 2 ohms and 7 ohms. Find their joint resistance when joined in series; when joined in parallel.

**4.** What is the difference in potential between two points in an electric circuit, carrying a current of 20 amperes, if the resistance of the circuit between the two points is 6 ohms?

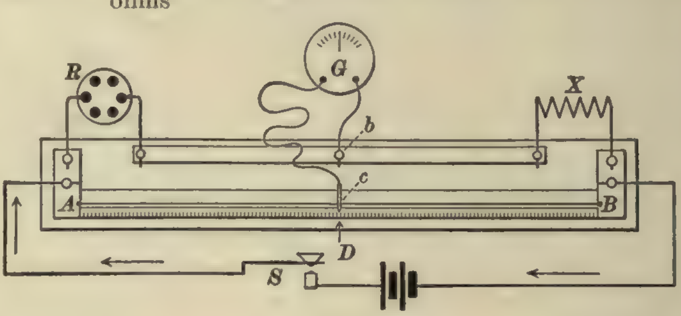
# 55. STUDY OF A CONDUCTOR

## RESISTANCE

**Apparatus.** Wheatstone's bridge; resistance box; 50-foot coil of No. 30 copper wire; 3-foot coil of No. 30 German-silver wire; sensitive galvanometer; 2 dry cells; switch.

### INTRODUCTION

We have learned that the amount of electricity flowing through a given circuit in a unit of time (see Ex. 52 and Ex. 54) is determined by (1) the electrical pressure behind the current and (2) the resistance offered by the circuit; $\text{amperes} = \frac{\text{volts}}{\text{ohms}}$. To regulate the current, then, we must be able to control either the resistance or the voltage, or both the resistance and the voltage. Since it has been found easier, in practice, to control the resistance than to control the voltage, we shall make a special study of the relative resistances of various conductors. For the accurate determination of small resistances the Wheatstone bridge, of the type known as the slide-wire bridge (see illustration), is commonly used in the laboratory. We shall make use of a similar piece of apparatus in this exercise. For a statement of the principle underlying the construction and operation of the instrument, consult the instructor. For interesting data concerning the electrical properties of wires, of various sizes and of different materials, see Appendix.



### EXERCISE

*Object.* To determine the resistance, in ohms, of a given length of wire of various kinds, and to learn how to use the Wheatstone bridge.

*Method.* 1. Assemble the apparatus as shown in the illustration, inserting the resistance box at *R* and the coil of wire, the resistance of which is to be measured, at *X*. One terminal of the galvanometer is to be connected by a wire with the central binding post *b* of the slide-wire bridge, and the other terminal is to be connected, by a longer wire, with the slider *c*. The terminals of the battery are to be connected, through the switch *S*, with the spare binding posts at opposite ends of the bridge. Place the slider *c* in the middle of the scale, remove the 10-ohm plug from the resistance box, close the switch *S*, and by means of the key on top of the slider *c* make contact for an instant with the resistance wire *AB*; observe the first swing of the galvanometer needle. Replace the 10-ohm plug in the resistance box, remove the 1-ohm plug, and repeat the experiment. Did the needle swing in opposite directions in the two cases? If so, the value of the unknown quantity *X* lies between 1 and 10 ohms; that is, the resistance of the coil of wire is greater than 1 ohm and less than 10 ohms. Try 6 ohms. Is this too large or too small? (*Suggestion:* A swing of the needle in the same direction as occurred when the 10-ohm plug was removed indicates a value larger than the unknown; a swing in the opposite direction indicates a value smaller than the unknown.) Experiment in this way until you are sure that you have obtained a value for *R* that is within 2 ohms of the value of *X*. Then, with the approximate value in circuit, move the slider back and forth along the wire until a point is found at which the galvanometer shows no movement whatever when contact is made at $c$. Note the position of the slider at this moment on the meter stick; measure the distance $AD$ from the end of the meter stick to the contact-point $D$, and compute the distance $DB$. Then, since the points $b$ and $D$ are at the same potential, $\frac{\text{Resistance } R}{\text{Resistance } X} = \frac{\text{Resistance } AD}{\text{Resistance } DB}$; or, briefly, since the resistance of a given conductor is proportional to the length of the conductor, $\frac{R}{X} = \frac{AD}{DB}$. Substitute the known values in the equation and find the value of $X$. Determine the resistance of each spool of wire; compute the resistance, in each case, of 100 ft. of wire of the same size and of the same material as the given wire. Compute the ratio between the resistance of 100 ft. of German-silver wire and that of 100 ft. of copper wire of the same size. Compare the results with the results obtained by the other members of the class and with the constants given in the Appendix.

2. Measure the resistance of some electrical instrument in which you are especially interested, and record.

Write up the exercise in good form, and report.

## PROBLEMS

**1.** How many feet of 30 per cent German-silver wire No. 30 is required for the construction of a 15-ohm resistance coil?

**2.** A telegraph line of No. 4 iron wire, one mile long, has what resistance? See wire tables in Appendix.

**3.** How many volts are required to force a current of 6 amperes through 1000 ft. of No. 14 copper wire? (See Ex. 54.) Is the wire large enough to carry the current safely?

**4.** Compute the resistance of 360 ft. of No. 8 iron wire. A current of how many amperes can be made to flow through this wire by the application of an electromotive force of 20 volts?

**5.** A pair of copper wires are to carry a current of 25 amperes I over a distance of 100 ft., with a potential drop E in the line of not over 3 volts. What size of wire should be used?

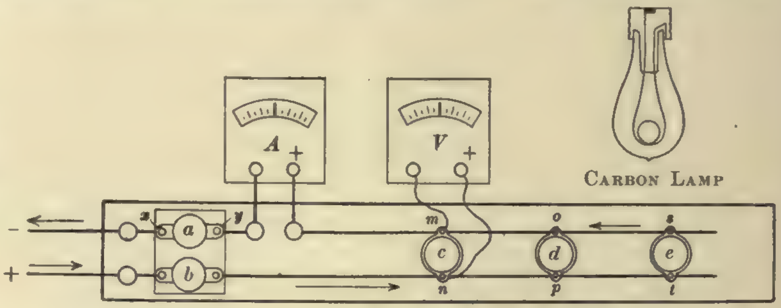
## 56. STUDY OF AN INCANDESCENT LAMP

### CURRENT CONSUMPTION; RESISTANCE

**Apparatus.** A main-line cut-out and three lamp sockets wired in parallel and mounted on a board with a break (bounded by two binding posts) in one side of the circuit, for the insertion of an ammeter; voltmeter, 0–150 volts; ammeter, 0–3 amperes; two tungsten lamps of known candle power, and one 16-candle-power carbon (or gem) lamp; 3-ampere fuse plugs.

### INTRODUCTION

The electric current which lights our houses, cooks our food, and drives our motors derives its energy from the electrical power developed by the dynamo at the central station. Electrical power is expressed in watts (volts × amperes). 1000 watts = 1 kilowatt. One kilowatt supplied for one hour = 1 kilowatt hour. We buy electricity by the kilowatt hour (kwh.). The rate varies with the locality; it runs all the way from 3¢ per kwh. to 19¢ per kwh. What is your local rate? Compute the cost of burning two 110-volt, ½-ampere incandescent electric lamps for ten hours at 10¢ per kwh. (*Suggestion:* $\frac{\text{Volts} \times \text{amperes}}{1000} \times \text{hr.} = \text{kwh.}$)



For suggestions concerning the use of ammeters and voltmeters see Ex. 53 and Ex. 54. Remember that voltmeters are to be connected *across* the line and ammeters *in* the line.

The unit for intensity of illumination employed by nearly all the manufacturers of incandescent electric lamps in this country is now the international candle, corresponding to the intensity of a standard incandescent electric lamp maintained at the National Bureau of Standards in Washington, D. C.; it is equivalent to about .95 standard candles (see Ex. 40).

### EXERCISE

*Object.* To determine the relative efficiency of a carbon and a tungsten incandescent electric lamp and to illustrate the method of wiring lamps in parallel.

*Method.* Assemble the apparatus as in the illustration; screw the fuse plugs into place at *a* and *b*, but do not turn on the current until your connections have been approved by the instructor.

1. *The carbon lamp.* Insert at *c* a fresh 16-candle-power carbon lamp, or a lamp the candle power of which has been recently determined by the use of a photometer (see Ex. 41), and screw it firmly into place. Turn on the current; read the voltmeter and the ammeter; compute (1) the watts consumed by the lamp, (2) the watts per candle power, (3) the cost per candle power hour, and (4) the hot resistance $\left(R = \frac{E}{I}\right)$ of the lamp.

2. *The tungsten lamp.* Substitute the tungsten lamp for the carbon lamp and repeat the experiment. Which lamp is the more economical of current? Would the cost per month of lighting a house of average size be less with tungsten lamps or with carbon lamps? What would be the difference? (*Note:* Consider the probable life, in hours, of each lamp and the cost of renewal.) Why are not tungsten lamps universally used?

3. *Lamps in parallel.* Screw a lamp into each of the three sockets. Determine, in succession, the number of amperes drawn by one lamp, by two lamps, and by three lamps, when connected in parallel. Is the resistance of three lamps, when connected in parallel, greater or less than the resistance of one lamp? Determine the potential difference (volts) across each of the lamps; that is, between the points *m* and *n* (see illustration), *o* and *p*, and *s* and *t*, respectively. Compare results. Conclusion? It is the business of the central station to keep the voltage across the mains of a parallel circuit constant (provided always that the mains are large enough) during any reasonable change in load. How well does our central station succeed in doing this?

4. *Lamps in series.* Insert a tungsten lamp at *a* in place of one of the fuses and insert the other tungsten lamp at *c*; lay aside the carbon lamp. The lamps are now connected in series; trace the connection. Turn on the current and read the ammeter. Is the combined resistance of the two lamps, when connected in series, greater or less than the resistance of one lamp? Connect the binding posts, in the main line, by a short, thick wire and disconnect the ammeter; determine the potential difference across each lamp separately and across the two lamps taken together; that is, between the points *x* and *y*, *m* and *n*, and *x* and *n*, respectively. Compare results. Conclusion? Why are not the lamps lighted to full brilliancy? What should be the voltage of each lamp if the two lamps, when connected in series across the mains of a 110-volt circuit, are to be lighted to full brilliancy? Extinguish one of the lamps by partially unscrewing the lamp from the socket. Why does the other lamp go out? Why does not the same thing happen when the lamps are connected in parallel? What advantages has parallel wiring over series wiring, for house-lighting? Write up the exercise in good form, and report.

### PROBLEMS

1. What would be the cost per month (120 hours), at 10¢ per kilowatt hour, of lighting a room with two 100-watt tungsten lamps?

2. Six incandescent lamps, taking .25 ampere each, are to be used in series across the mains of a 500-volt trolley line. What must be the voltage of each lamp? What will be the resistance of each lamp? How many watts will each lamp consume? What will be the approximate candle power of each lamp?

### TOPICS FOR FURTHER STUDY AND INVESTIGATION

Manufacture of incandescent electric lamps.
Varieties of incandescent lamps: nitrogen-filled, metallized-filament, daylight.
Arc lamps: Cooper-Hewitt, flaming-arc.
Indirect lighting.
Use of shades.
The watt-hour meter (see Ex. 57).

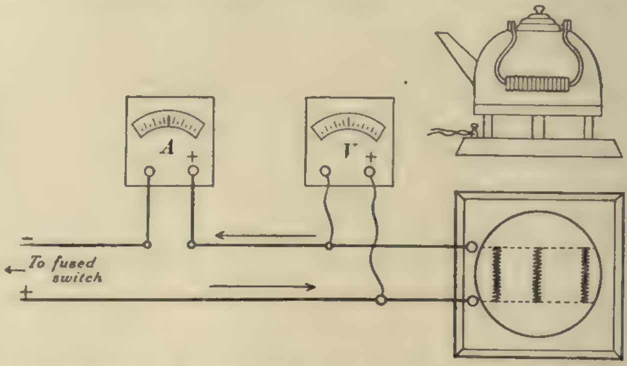
# 57. STUDY OF AN ELECTRIC STOVE

## EFFICIENCY

**Apparatus.** Electric stove or hot plate; teakettle or saucepan and cover; ammeter, 0–15 amperes; voltmeter, 0–150 volts; Fahrenheit thermometer; scales.

### INTRODUCTION

Precisely as mechanical energy may be transformed into heat by friction, so electrical energy may be transformed into heat by resistance (see Ex. 52 and Ex. 56). Advantage is taken of this fact in the construction and operation of the various kinds of electric heaters now on the market. The heating element of an electric stove or hot plate consists of a ribbon of metal, of high specific resistance, embedded in enamel (or supported on a frame) and so arranged that its terminals may easily be connected with the terminals of an electric service or other source of electricity (see illustration). In practice an incandescent lamp is often installed between the switch and the stove, or between the switch and the flatiron, to show at a glance whether the current is on or off, and so to serve as a protection against possible danger from fire, due to carelessness in leaving the heating element aglow when the device is supposed to be turned off. The quantity of heat developed by the current may be computed from the following formula: British thermal units (B.T.U.) = $\frac{\text{watts} \times \text{seconds}}{1055}$, or calories = .24 × watts × seconds. To determine the efficiency of the electric stove and kettle combined we must find the ratio between the B.T.U. absorbed by the water (output) and the B.T.U. developed by the current (input). To determine the efficiency of the stove alone we must find the ratio between the B.T.U. absorbed by the water and the kettle (output) and the B.T.U. developed by the current (input) (see Ex. 21 and Ex. 23).



### EXERCISE

*Object.* To determine the efficiency of an electric stove or hot plate when used to heat a quantity of water in a teakettle or a saucepan.

*Method.* Connect the apparatus as shown in the illustration, the ammeter *in* the line and the voltmeter *across* the line, but do not turn on the current until your connections have been approved by the instructor. Turn on the current and allow it to run for about five minutes, to heat up the stove, before you put on the kettle.

Find the weight, in pounds, of the kettle. Fill the kettle two-thirds full of water and weigh it again; record. Stir the water thoroughly with the thermometer and record its temperature. Place the kettle on the stove and secure it firmly in place; note the exact time. Read the voltmeter and the ammeter at regular intervals during the entire run, and record the average reading of each instrument. Before the water reaches its boiling point (preferably at about 180° F.), take the temperature of the water as before, and record; note the exact time and turn off the current. Compute the change in temperature in degrees Fahrenheit, and the time of the run in seconds.

1. Compute the number of B.T.U. absorbed by the water and the number of B.T.U. developed by the current; compute the efficiency of the stove and the kettle.

2. Compute the number of B.T.U. absorbed by the kettle (weight × .1 × change in temperature), add the B.T.U. absorbed by the water, and compute the efficiency of the stove. Account for low efficiency. Suggest improvements.

3. Determine the cost, at the local rate per kilowatt hour, of raising the temperature of a quart of water, by use of the electric stove employed in this exercise, from the temperature of the room to the boiling point. Compare with the results obtained by the use of alcohol, gas, and kerosene. Record your results in good form, and report.

## TOPICS FOR FURTHER STUDY AND INVESTIGATION

Cost per hour of running various electric heating appliances of the household, such as toasters, coffee percolators, and flatirons. The cost can be computed from the data (normal consumption in watts) recorded on the instrument or given in the manufacturer's catalogue, and the known cost per kilowatt hour of the electricity supplied as follows: $\text{Cost per hour} = \frac{\text{watts}}{1000} \times \text{cost per kilowatt hour}$. Results may be checked by the use of either a wattmeter or a watt-hour meter, if either instrument is available.

*Home study.* Hunt up the watt-hour meter in your house, if the house is lighted by electricity, and observe the revolving disk seen through the glass window in the case. If the given meter is not listed in the table below, send the name, size, and number of the instrument to the manufacturer of the apparatus and ask him to tell you how many watt hours are represented by one revolution of the disk. Upon receipt of the desired information, experiment as follows: Determine the number of revolutions per minute made by the disk while a given appliance, such as an electric lamp or a percolator, is in use on the house circuit, and compute the cost per hour. See formula.

### DISK CONSTANTS FOR VARIOUS TYPES OF WATT-HOUR METERS

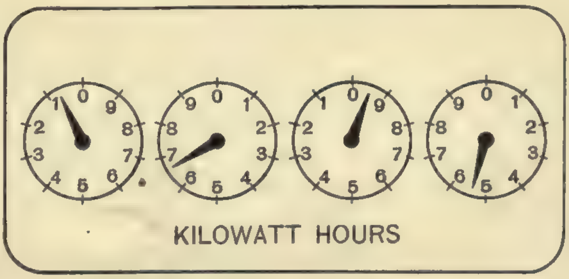
### WATT HOURS PER REVOLUTION (K)

| | |
|---|---|
| Sangamo, type II | .208 |
| Westinghouse, types B, C, and O A | .333 |
| Fort Wayne, type 1–10 | .250 |
| General Electric, types 1 and 1–14 | .030 |

The table is given for 5-ampere, 110-volt, 60-cycle, two-wire meters. The constants for instruments of larger capacity are proportional. To compute the cost per hour for a given run, make use of the following formula:

$$\text{Cost per hour} = \frac{\text{revolutions per minute} \times 60 \times K}{1000} \times \text{cost per kilowatt hour.}$$

The watt-hour dial (see illustration) is read like a gas-meter dial, except that no ciphers need be added, the result being indicated directly in kilowatt hours. The reading of the dial shown in the illustration is 695 kilowatt hours. For suggestions concerning a possible slipping of the hands, see Ex. 5.



Read your home meter on two separate occasions, preferably one month apart, and report the cost, at the local rate per kilowatt hour, of the electricity consumed during the interval.

Underwriters' Rules. The National Electrical Code is a set of rules and regulations issued by the National Board of Fire Underwriters for the guidance of contractors and workmen engaged in electric wiring and the installation of electric fixtures. The code is revised once in two years and is designed to protect the public against the occurrence of fires caused by defective wiring or by the use of the wrong fixture; it is fast becoming the standard for this country. "Approved" fittings are fixtures that have been tested and accepted as safe by the underwriters. A copy of the code may be procured from almost any electrical supply house.

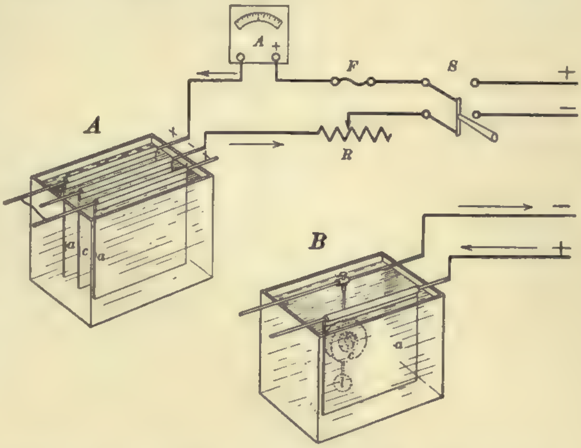
What do the rules specify under the following topics?

Wires: smallest size allowable for interiors; in wet places; stranded; carrying capacity. Automatic cut-outs; fuses. Electric heaters. Flexible cord. Moving-picture equipments for home use. Garages. Fuse test. Wireless apparatus.

## 58. STUDY OF ELECTROLYSIS

### ELECTROPLATING; ELECTROTYPING

**Apparatus.** A rectangular glass jar, of any convenient size; three copper strips, about 3 in. × 4 in. × $\frac{1}{16}$ in. (two to serve as anodes and one to serve as a cathode), and three supports; $\frac{1}{2}$ lb. copper sulphate; 1 oz. sulphuric acid; alcohol; beeswax; paraffin; powdered graphite, or plumbago; solder.



#### INTRODUCTION

The discovery, in 1800, of electrolysis, or the process by which the metals may be separated, through the use of electricity, from certain of their compounds known as salts, and be deposited subsequently, in the form of a thin layer, upon solid objects through the same agency, made possible the marvelous development of the modern art of electroplating with gold, silver, nickel, and platinum, and the allied art of electrotyping, or the reproduction, in copper, in gold, in silver, or in platinum, of such objects as coins, shells, insects, flowers, and printer's type. The entire subject is obviously too extensive to be treated at length within the limits of a laboratory exercise; we shall therefore confine ourselves to a brief study of the electroplating of a metal with copper and the reproduction in copper of a small medal or a coin. *Note:* The reproduction of United States coins or the coins, in current circulation, of any other nation is forbidden by law.

*Definition.* An ampere may be defined as the rate of flow of a current of electricity that will deposit .001118 g. of silver per second from a 15 per cent solution (by weight) of silver nitrate, or .0197 g. of copper per minute from a solution of copper sulphate consisting of 10 g. of copper sulphate and 40 cc. of distilled water.

#### EXERCISE

*Object.* To illustrate the art of electroplating and the art of electrotyping, and to make clear the meaning of the word *ampere.*

*Method.* 1. Fill the jar nearly full of a saturated solution (or a solution of specific gravity 1.16 as shown by a hydrometer) of copper sulphate to which a small quantity of sulphuric acid and a few drops of alcohol have been added; suspend the two anodes, *a*, *a* (see illustration, A), side by side in the solution and about 1 in. apart, from a pair of heavy copper wires laid across the top of the jar; join the wires and connect the two anodes, through the ammeter, the fuse F, and the switch S, with the + pole of the battery or dynamo; suspend the cathode *c* between the two anodes, and connect the cathode, through the rheostat R and the switch S, with the − pole of the battery or dynamo; set the rheostat to give a small current, and close the switch; adjust the rheostat until the ammeter reads $1\frac{1}{2}$ amperes, and allow the current to flow for about three minutes; open the switch and examine the cathode. A smooth deposit of fresh copper shows that the apparatus is working properly. A feathery deposit of a reddish-brown powder shows that the current is too strong; in such a case, rinse the cathode in clear water, reduce the strength of the current, and try again. Adjust the rheostat until a satisfactory deposit is obtained, and report to the instructor.

2. Scour the cathode with emery paper or with sandpaper; rinse the cathode in clear water and dry it over a Bunsen burner (taking care not to touch the smooth surface of the cathode with the bare fingers), and find its weight to a centigram; suspend the cathode in the solution as before and turn on the current; note the exact time. Read the ammeter once in every five minutes for half an hour; remove the cathode from the solution; note the exact time; dry the cathode over a Bunsen burner and weigh it again. Compute the number of grams of copper deposited per minute and the average strength of the current in amperes (.0197 g. per minute = 1 ampere). Compare the result with the average reading of the ammeter. Conclusion?

3. Melt a mass of beeswax, or a mixture of beeswax and paraffin (half and half), onto a piece of cardboard. Allow the mass to cool until a smooth, tough surface is obtained; by means of a camel's-hair brush, dust the smooth surface of the wax with powdered graphite; rub the graphite in with the ball of the finger until the surface of the wax becomes uniformly smooth and shiny. Soften the wax by holding it over a flame; force the medal steadily down into the wax until you feel sure that a good impression has been obtained; allow the mass to cool, and remove the medal. Fasten a copper wire to the cardboard, make a good electrical connection between the wire and the mold by dusting the two with graphite; hang the pasteboard, in the place of the cathode plate and facing one of the anodes, in the copper sulphate solution, holding the whole in place, if necessary, by means of a lead weight *l* (see illustration, B) attached to the lower end of the cardboard, and turn on the current. Regulate the strength of the current until a good deposit begins to appear on the graphite mold. Continue the process for an hour, or until a thick deposit of copper has coated the entire mold. Remove the wax from the solution and, by the aid of a penknife, pick the electrotype out of the mold; the exposed surface should represent a perfect copy of the face of the medal, "done in copper." Trim the edges of the replica and fill the back with solder to stiffen it. Make a duplicate of the other side of the medal and mount the two replicas side by side, or solder the two parts together back to back and make a complete medal.

See Monograph B–5, published by the Weston Electrical Instrument Co., Newark, N.J.

## PROBLEMS

**1.** A current of how many amperes is required to deposit 2 oz. of silver from a silver bath in 3 hours?

**2.** Suggest a possible method of measuring, without the aid of an ammeter, the strength of current used in a given circuit.

**3.** Account for the deposit of fresh copper often seen on the copper plate of a Daniell cell that has been in use for some time.

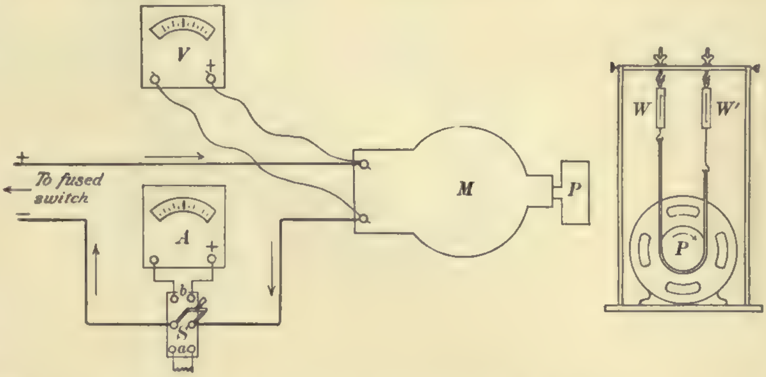
## TOPICS FOR FURTHER STUDY AND INVESTIGATION

Copperplate engraving.
Electrotyping of books and magazines.
Nickel-plating.
Electrolysis of water.
Storage cells.

# 59. STUDY OF AN ELECTRIC MOTOR

## EFFICIENCY

**Apparatus.** D.C. (direct current) motor; voltmeter, 0–150 volts; ammeter, 0–15 amperes; double-throw switch, fitted at one end with a resistance coil adapted to the particular motor employed, and designed to absorb the sudden rush of current which occurs at the instant of starting the motor; rope brake, consisting of a leather strap lined with asbestos; two spring balances and support, or spring balance, pulley, set of weights, and support (see Ex. 6); speed counter; stop watch or other timepiece; source of electricity, D.C. 110 volts.



### INTRODUCTION

Power is rate of doing work. Mechanical power is measured in foot pounds per minute. Electrical power is measured in watts (volts × amperes). 1 horse power = 746 watts. The *output* of an electric motor (brake horse power, B.H.P.) may be determined by the application of a rope brake or a Prony brake (see Ex. 6 and Ex. 33) to the pulley; the *input* (electrical horse power, E.H.P.) may be determined by multiplying the rate of flow (amperes) by the electrical pressure (volts) and dividing the result by 746. $\frac{\text{Watts}}{746} = \text{horse power}$. $\text{Efficiency} = \frac{\text{output}}{\text{input}}$.

### EXERCISE

*Object.* To determine the efficiency, under various loads, of an electric motor.

*Method* (for two pupils, A and B, working together). Arrange the apparatus as in the illustration, the ammeter *in* the line and the voltmeter *across* the line, but do not close the circuit until your connections have been approved by the instructor. Start the motor $M$ by throwing the switch $S$ to the starting end $a$; keep the switch at the starting end until the motor has attained a uniform speed, and then throw the switch to the running end $b$. Increase the tension on the brake (by raising the spring balances) until the motor slows perceptibly, and observe the readings of the two balances; the difference, $W' - W$, between these two readings represents the load on the motor. To keep the load constant during any given run, watch the ammeter and adjust the balances accordingly; a constant ammeter reading means a constant load. Why does the reading of the ammeter increase with an increase in the load? Make the first run with a small load, as indicated by a small reading ($\frac{1}{2}$ ampere) of the ammeter, and increase the load by a small amount at the beginning of each new run. Gather all the data required for the tabular statement (see *Form of Record*); make the required computations and complete the record.

The work of gathering the data may be divided between the two pupils somewhat as follows: Duties of pupil A: Adjust the tension on the brake until the required ammeter reading is obtained; at the beginning of an even minute, as shown by the watch, say "Go" to pupil B and observe the reading of the ammeter; note the average reading of the ammeter during the run and the average reading of each of the two balances; try to keep the load constant; at the end of the first minute say "Stop" to pupil B and release the brake. Duties of pupil B: Note the initial reading of the speed counter; at the word "go" press the spindle of the speed counter against the end of the motor shaft and hold it steadily in place; note the average reading of the voltmeter; at the word "stop" instantly remove the speed counter and note the reading of the instrument; compute the number of revolutions per minute of the motor; measure the diameter of the pulley and compute the radius of the pulley.

Make repeated trials of the efficiency of the motor under various loads; plot a curve between the load and the efficiency, and report.

(*Form of Record*)

STUDY OF AN ELECTRIC MOTOR: EFFICIENCY

*Data*

| Voltmeter<br>$E$ | Ammeter<br>$I$ | Balances<br>$W'$ | <br>$W$ | Speed counter<br>$N$ | Radius of pulley<br>$R$ |
|---|---|---|---|---|---|
| | | | | | |

*Computations*

| Input<br>E. H. P. | Output<br>B. H. P. | Efficiency<br>% | Cost per horse-power hour at<br>10¢ per K.W.H. |
|---|---|---|---|
| $\frac{E \times I}{746}$ | $\frac{2\pi R(W' - W)N}{33{,}000}$ | $\frac{\text{Output}}{\text{Input}}$ | Cents per hour |
| | | | |

*Conclusion*

Note. The radius of the pulley should be expressed in feet, and the readings of the balances in pounds. Why?

## TOPICS FOR FURTHER STUDY AND INVESTIGATION

Classes of motors: shunt motors; series motors; compound motors.

Starting boxes or rheostats; diagrams and connections.

Methods of starting various kinds of motors. *Suggestion:* To start a shunt motor: Close the main switch; move the swinging arm of the starting box *slowly* over the contact points until the arm reaches the stop at the end of the arc; do not pause for any great length of time at any intermediate point, or the starting resistance may be burned out. To stop the motor: Open the main switch; the lever of the starting box will fly back, of itself, to the starting position.

Overload release: no-voltage release.

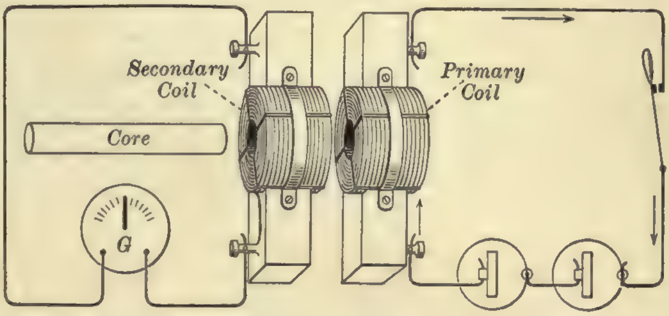
## 60. STUDY OF INDUCED CURRENTS

### PRINCIPLE

**Apparatus.** Two Gilley coils; soft-iron core; circuit closer or Morse telegraph key; two dry cells; sensitive galvanometer; magnetic compass; connecting wires.

### INTRODUCTION

We have seen (Ex. 50) that a magnetic field of force can be established about a coil of wire by the passage of a current of electricity through the wire. Is the experiment reversible? That is, can a current of electricity be generated in a coil of wire by the setting up of a magnetic field of force about the wire? To answer this question is the object of the exercise.



### EXERCISE

*Object.* To study the effect of a varying magnetic field of force upon a coil of wire forming part of a closed circuit.

*Method.* Connect one of the coils in series with the circuit closer and two of the dry cells; we shall speak of the coil in this circuit as the primary coil. Connect the other coil with the galvanometer; we shall speak of the coil in this circuit as the secondary coil. Place the coils side by side, with their axes in the same straight line, as in the illustration. Omit the core.

1. Close the circuit through the primary coil and observe the effect on the galvanometer; open the circuit and again observe the effect on the galvanometer. Open and close the circuit a number of times in rapid succession; observe the effect on the galvanometer. Conclusion? The momentary effect observed in the secondary coil is said to be induced by the opening and closing of the circuit through the primary coil; it is caused, in fact, by the sudden establishment and withdrawal of the magnetic lines of force generated by the current flowing through the primary coil.

2. By means of a magnetic compass, placed in turn under each wire and at some distance from the coil, determine, in each case, the direction of the current in the primary coil and the direction of the momentary current generated in the secondary coil.

Answer the following questions: Does the induced current in the secondary coil, caused by opening the circuit through the primary coil, run in the same direction as the current in the primary coil or does it run in the opposite direction? Does the induced current in the secondary coil, caused by closing the circuit through the primary coil, run in the same direction as the current in the primary coil or does it run in the opposite direction? How can an alternating current (a current that runs first one way and then the other) be produced in the secondary coil by the use of a direct current in the primary coil? What determines the frequency (number of alternations per second) of this alternating current? What effect should be produced by the substitution, in the primary circuit, of a vibrating electric bell for the circuit closer? Try it. What effect should be produced by a sudden increase in the magnetic lines of force surrounding a conductor? by a sudden decrease?

3. Slip the soft-iron core through the coils and repeat the experiment. Explain the effect of the soft-iron core.

4. (Optional.) Set aside the battery and the soft-iron core; connect the primary coil *in series* with a 25-watt, 110-volt incandescent electric lamp and a switch; place the coils close together; connect the ends of the primary circuit to the terminals of a 110-volt A.C. (alternating current) electric current; close the switch and watch the galvanometer in the secondary circuit. Observation? Conclusion? Substitute a telephone receiver for the galvanometer; close the primary circuit; place the receiver to your ear and account for what you hear; move the coils farther apart and repeat the experiment; slip the soft-iron core through the coils and again repeat the experiment; try the effect of opening and closing the primary circuit. Substitute a D.C. current for the A.C. current and repeat the entire series of observations. Grand conclusion? Write up the exercise in good form, and report.

### PROBLEMS

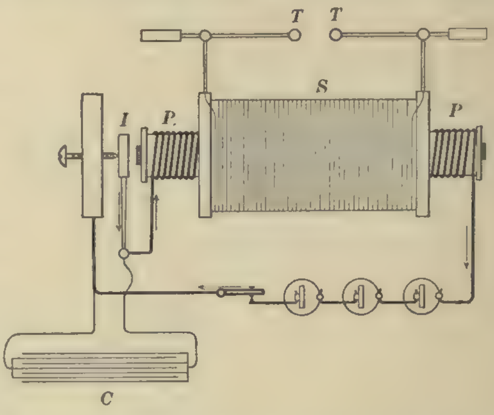
1. What is the use of the interrupter, or trembler, in an induction coil?

2. The secondary of an induction coil consists of 15,000 turns of wire; the primary contains 50 turns of wire. What will be the E.M.F. of the secondary coil if the E.M.F. of the primary coil is 10 volts?

3. The primary of a step-down transformer consists of 2000 turns of wire. How many turns of wire must the secondary contain if the E.M.F. is to be stepped down from 2000 volts to 125 volts?

4. What would be the result if a step-down transformer were connected the wrong way around; that is, the terminals of the coil of coarse wire connected to the street mains and the terminals of the coil of fine wire to the lighting circuit of the house?

### TOPICS FOR FURTHER STUDY AND INVESTIGATION



Induction coils and transformers. An induction coil is a device for raising the voltage, or the electromotive force (E.M.F.), of an electric current. The device consists of two independent coils of insulated wire wound upon a core of soft-iron wire; the inner coil, or primary coil, *PP* (see illustration), is composed of a comparatively few turns of coarse wire, while the outer coil, or secondary coil, *S*, is made up usually of several thousand turns of fine wire. The primary circuit is opened and closed, automatically and with great rapidity, by an interrupter *I* which works precisely like the hammer of a vibrating electric bell (see Ex. 51). The abrupt opening and closing of the primary circuit induces an electromotive force, in the secondary circuit, of such an intensity that the resulting current leaps across the gap *TT* between the terminals of the secondary coil and produces a series of brilliant sparks. The voltage ($V$) across the terminals of the secondary coil is practically in the same ratio to the voltage ($v$) across the terminals of the primary coil as the number of turns ($N$) of the secondary coil is to the number of turns ($n$) of the primary coil; that is, $V : v = N : n$. The gain in voltage is balanced by the loss in amperage. A condenser *C*, connected across the terminals of the interrupter, increases the efficiency of the apparatus by making the break more abrupt. Induction coils have been constructed containing many millions of turns of wire and capable of producing a spark 10 ft. long.

Examine a small induction coil; operate the apparatus; pass the spark through a small Geissler tube, or across the terminals of a spark plug, and explain the action of the apparatus.

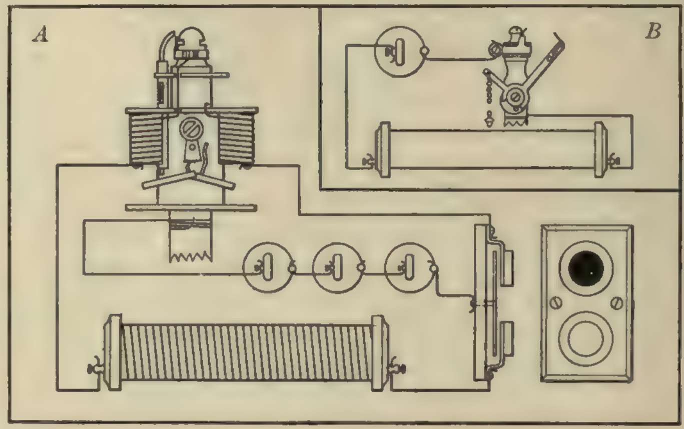
Uses of induction coils: X-rays; jump-spark coils for gas-engine ignition; medical coils; wireless transmitters.

A transformer is an induction coil of a special form designed to change the voltage of an alternating electric current. The iron box seen perched on the electric pole in front of certain houses lighted by electricity is usually a step-down transformer designed to drop the voltage of the street mains from perhaps 2000 volts to 110 volts, or to 220 volts in some cases, for use in connection with electrical appliances used in the household. The current enters the transformer through the coil of coarse wire, and the induced current is taken off from the terminals of the coil of fine wire; no interrupter is required. The voltage is dropped (stepped down) in proportion to the ratio between the turns of wire in the respective coils. The toy transformers, used to ring electric bells and to run electric toys, work on the same principle as the commercial transformer, stepping the voltage down from 110 volts to 3, 6, or 8 volts. Investigate the subject and write an article on "The Transformer."

## 61. STUDY OF IGNITION

### GAS-LIGHTING

**Apparatus.** Two gas burners, — one a pendent burner (lighting from a chain pull) and the other an automatic burner (lighting from a push button), — mounted separately on a short piece of gas-pipe and provided with a hose connection for convenient attachment to a gas supply; spark coil, consisting of a bundle of soft-iron wire, ¾ in. in diameter and about 8 in. long, wound with at least 200 turns of No. 18 insulated copper wire; double push button fitted with one white knob and one black knob; three dry cells; insulated wire for connections.



#### EXERCISE

*Object.* To study the method of wiring a house for electric gas-lighting and to learn the use of a spark coil.

*Method.* 1. Connect the spark coil and the dry cells in series; open the circuit at any convenient point and observe the bright spark formed at the break. Close the circuit; short-circuit the coil, by connecting the ends of the coil through a short piece of copper wire, and again open the circuit. Observation? The effect of the coil is due to self-induction: a portion of the coil acts like the primary of an induction coil (see Ex. 60), while the rest of the coil acts like the secondary of the same induction coil; the collapse of the magnetic field, due to the sudden break in the circuit, causes a momentary induced current of high potential to flow through the coil; the induced current jumps across the gap and forms a spark.

2. Connect one of the dry cells, the spark coil, and the pendent burner, in series (attaching one end of the wire to the small screw in the insulated ring at the top of the burner and the other end of the wire to the gas-pipe at any convenient point), as shown in the illustration, *B*. Turn on the gas and give the chain a sharp pull. If the gas does not light at the first attempt, try again, but do not allow any considerable amount of gas to escape into the room. Add more cells if necessary. Sketch the essential parts of the apparatus and describe the action of the burner.

3. Connect the spark coil, the push button, the automatic burner, and the battery as in the illustration, *A*. Push the white button and hold it until the gas lights. Push the black button. Observation? Examine the mechanism of the burner and describe the action of its several parts. *Suggestion:* The iron gas-pipe forms a part of the electric circuit.

4. Connect the apparatus in such a manner that either burner may be lighted at will. *Suggestion:* Connect the automatic burner first and then connect the pendent burner, in parallel, with the automatic, using but one wire for the gas-pipe connection.

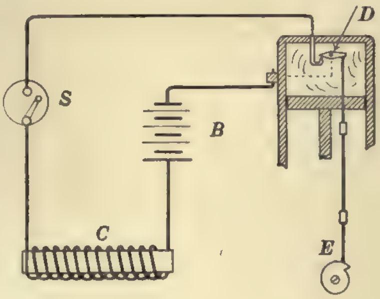
Write up the exercise in good form, and report.

#### TOPICS FOR FURTHER STUDY AND INVESTIGATION

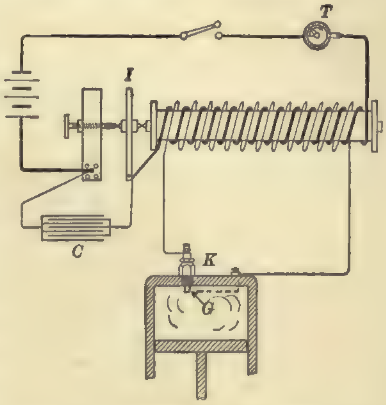
Devices for protecting high-potential switches from injury due to the spark formed at the instant of opening the circuit.

Wiring connections for a gas-lighting system consisting of three automatic burners, two pendent burners, one spark coil, and a battery. Make a diagram.

Principle of wiring for a small marine engine; make-and-break spark. The spark coil *C* (see illustration), the switch *S*, and the battery *B* are connected in series; one end of the circuit is attached (grounded) to the framework of the cylinder, and the other end of the circuit is attached, through a heavily insulated wire, to a device *D*, placed at the top of the cylinder, for opening and closing the circuit inside the cylinder. The circuit is closed, at the right moment, through the operation of a cam *E* attached to the main shaft of the engine, and abruptly opened again; the sudden break produces a spark inside the cylinder, which ignites the mixture (air and gasoline); the resulting explosion pushes the piston forward and drives the engine.

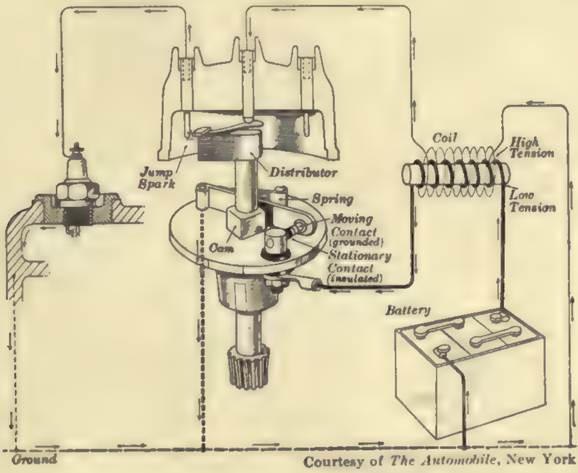


Principle of wiring for an automobile engine; jump spark. The secondary terminals of an induction coil are attached, one on either side, to a spark gap *G* (see illustration) placed at the end of a spark plug *K* which terminates inside the cylinder. The primary circuit is opened and closed, automatically and at the right time, by a rotating device *T* (known as a timer) which is operated by a cam attached to the main shaft of the motor; the current induced in the secondary coil by the opening and closing of the primary circuit through the trembler *I* (interrupter, see Ex. 60) jumps across the gap *G* and fires the charge. A condenser *C*, connected across the terminals of the interrupter, serves to increase the abruptness of the break and to improve the spark. In practice the ignition system of an average automobile engine is considerably more complicated than would appear from these simple diagrams; the coil is often made an integral part of the magneto which takes the place of the battery, and the parts are entirely concealed; a distributor is added, to make sure that each cylinder is fired at the critical moment, and the trembler (interrupter) is often omitted. The fundamental principles, however, have been clearly shown: variations are left to the pupil.



Report as fully as possible upon some system of gas-engine ignition with which you are familiar or in which you are especially interested. See catalogues and instruction books furnished by the various manufacturers.

Explain the action of the apparatus shown in the illustration below.



Courtesy of *The Automobile*, New York

# APPENDIX

## TABLE OF DENSITIES OF VARIOUS WOODS *

| | Grams per cubic centimeter | Average | Pounds per cubic foot | Average |
|---|---|---|---|---|
| 1. Birch | .51–.77 | .64 | 37–48 | 40 |
| 2. Box | .95–1.16 | 1.08 | 59–72 | 66 |
| 3. Cedar | .49–.57 | .53 | 30–35 | 33 |
| 4. Cherry | .70–.90 | .80 | 43–46 | 45 |
| 5. Cork | .22–.26 | .24 | 14–16 | 15 |
| 6. Ebony | 1.11–1.33 | 1.22 | 69–83 | 76 |
| 7. Lignum Vitæ | 1.17–1.33 | 1.25 | 73–83 | 78 |
| 8. Mahogany (Honduras) | .56 | .56 | 35 | 35 |
| 9. Mahogany (Spanish) | .85 | .85 | 53 | 53 |
| 10. Maple | .62–.75 | .69 | 39–47 | 43 |
| 11. Pine, red | .48–.70 | .59 | 30–44 | 37 |
| 12. Pine, white | .35–.50 | .43 | 22–31 | 27 |
| 13. Pine, yellow | .37–.60 | .49 | 23–37 | 30 |
| 14. Oak | .60–.90 | .75 | 37–56 | 47 |
| 15. Walnut | .64–.70 | .67 | 40–43 | 42 |

* From Smithsonian reports

## COMPOSITION OF ALLOYS

| | Tin | Antimony | Lead | Copper | Zinc | Nickel |
|---|---|---|---|---|---|---|
| Brass | | | | 72 | 28 | |
| Brass (yellow) | | | | 60 | 40 | |
| Gun metal | 91 | | | | 9 | |
| Babbitt metal | 45.5 | 13 | 40 | 1.5 | | |
| Pewter | 80 | | 20 | | | |
| Soft solder | 50 | | 50 | | | |
| Type metal | 3 | 15 | 82 | | | |
| Bronze | 94 | | | 1 | 5 | |
| German silver (30%) | | | | 50 | 20 | 30 |

## HEAT VALUES OF FUEL*

| | |
|---|---|
| Alcohol | 12,000 B.T.U. per pound |
| Anthracite coal | 13,000 B.T.U. per pound |
| Bituminous coal | 13,000 B.T.U. per pound |
| Gasoline | 19,000 B.T.U. per pound |
| Kerosene | 18,000 B.T.U. per pound |
| Peat | 10,000 B.T.U. per pound |

## HIGH TEMPERATURES

| | |
|---|---|
| Bunsen burner | 3,400° F. |
| Tungsten lamp (1.0 watt per candle) | 3,800° F. |
| Oxy-hydrogen flame | 5,070° F. |
| Oxy-acetylene flame | 6,330° F. |
| Electric arc | 6,330° F. |
| The sun | 10,800° F. |

* Bureau of Standards, Washington, D. C.

## WIRE TABLE

| Number B. and S. gauge | Diameter in mils (1 mil = .001 inch) | Area in circular mils | Resistance per 1000 feet in ohms | Carrying capacity in amperes | |
|---|---|---|---|---|---|
| 00 | 364.8 | 133,080* | .078 | 150† | 225 |
| 1 | 289.3 | 83,694 | .124 | 100 | 150 |
| 4 | 204.3 | 41,742 | .248 | 70 | 90 |
| 10 | 101.8 | 10,381 | .997 | 25 | 30 |
| 12 | 80.8 | 6,530 | 1.59 | 20 | 25 |
| 14 | 64.1 | 4,107 | 2.52 | 15 | 20 |
| 16 | 50.8 | 2,583 | 4.01 | | |
| 18 | 40.3 | 1,624 | 6.37 | | |
| 24 | 20.1 | 404 | 25.6 | | |
| 30 | 10.0 | 100 | 103. | | |
| 36 | 5.0 | 25 | 414. | | |
| 40 | 3.1 | 10 | 1047. | | |

* For area of stranded wire take the sum of the circular-mil areas of the separate strands.

† The figures given in this column are for rubber-covered wires; the figures in the last column are for wires of any approved insulating material except rubber.

To find the resistance of a given wire made of some other material than copper, proceed as follows:

Find the resistance of a copper wire of the same size and length as the given wire and multiply the result by the number set opposite the given material in the table below:

## COMPARATIVE RESISTANCE OF VARIOUS METALS

| | | |
|---|---|---|
| Aluminum, 1.5. | 18% German silver, 19. | "Ia," 28. |
| Platinum, 6. | "Yankee silver," 20. | "Climax," 50. |
| Norway iron, 7. | 30% German silver, 28. | "Nichrome," 60. |

## TELEGRAPH CODE

| | Morse | Continental |
|---|---|---|
| A | •— | •— |
| B | —••• | —••• |
| C | •• • | —•—• |
| D | —•• | —•• |
| E | • | • |
| F | •—• | ••—• |
| G | ——• | ——• |
| H | •••• | •••• |
| I | •• | •• |
| J | —•—• | •——— |
| K | —•— | —•— |
| L | ⸺ | •—•• |
| M | —— | —— |
| N | —• | —• |
| O | • • | ——— |
| P | ••••• | •——• |
| Q | ••—• | ——•— |
| R | • •• | •—• |
| S | ••• | ••• |
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